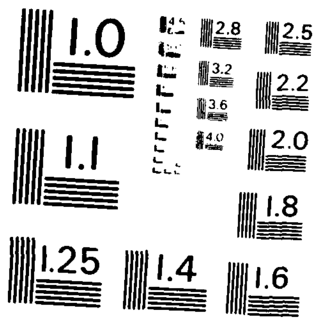
AD-A131 425 NUCLEAR WARFARE WATER CONTAMINATION(U) SCIENCE APPLICATIONS INC SCHAUMBURG IL J C PHILLIPS ET AL. 01 MAY 82 DNA-TR-81-127 DNA001-81-C-0234 1/3

UNCLASSIFIED F/G 15/6 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

(12)

DNA-TR-81-127

NUCLEAR WARFARE WATER CONTAMINATION

Science Applications, Inc
Chicago Office
One Woodfield Place Building
1701 E. Woodfield Road
Schaumburg, Illinois 60195

1 May 1982

Technical Report

CONTRACT No. DNA 001-81-C-0234

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

THIS WORK WAS SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER RDT&E RMSS CODE X384081469 Q22QAXNA00001 H2590D.

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: DNA-TR-81-127	2. GOVT ACCESSION NO.: AD-A131 [illegible]
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): NUCLEAR WARFARE WATER CONTAMINATION	5. TYPE OF REPORT & PERIOD COVERED: Technical Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): J. C. Phillips, J. A. Roberts, R. H. Sievers, and R. Gminder	8. CONTRACT OR GRANT NUMBER(s): DNA 001-81-C-0234
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Science Applications, Inc., Chicago Office, One Woodfield Place Bldg., 1701 E. Woodfield Road, Schaumburg, Illinois, 60195	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Task Q22QAXNA-00001
11. CONTROLLING OFFICE NAME AND ADDRESS: Director, Defense Nuclear Agency, Washington, D. C., 20305	12. REPORT DATE: 1 May 1982
	13. NUMBER OF PAGES: 222
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work was sponsored by the Defense Nuclear Agency Under RDT&E RMSS Code X384081469 Q22QAXNA00001 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Water
Fallout
Contamination
Nuclear Warfare
Water Purification
Water Decontamination
Radiation Monitoring

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The fallout contamination of watersheds and water supplies resulting from surface burst nuclear weapons is sufficiently high to require the use of water purification equipment to produce potable water that meets the current radiological water quality standards. Problems with existing radiation detection and monitoring equipment are discussed. A water contamination model is described.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1

INTRODUCTION

In the event of nuclear warfare, the raw water supplies available to U. S. Army field units could become radiologically contaminated. Water is essential to the health and hygiene of personnel; radiologically contaminated water poses a physiological, and pyschological, threat to personnel who are expected to perform effectively in a radiologically contaminated environment. To address the potential threat of contaminated water, the U. S. Army has guidelines and standards for water quality, equipment and procedures for the radiological monitoring of water, and equipment and procedures for the purification of contaminated water.

This assessment of the nuclear warfare water contamination threat is principally concerned with the equipment and procedures for the monitoring and purification of radiologically contaminated water. The assessment does not explicitly address water quality standards; however, the standards are discussed in terms of the technical performance criteria that they provide for the water monitoring and purification equipment.

The objective of this water contamination threat assessment are: (1) to characterize the contamination threat, (2) to identify field methods for recognizing the contamination threat, and (3) to indicate the effectiveness of possible threat countermeasures. The assessment is focused on the water contamination threat associated with nuclear warfare in Europe and is primarily concerned with the contamination of rivers and streams by the fission products produced by a nuclear weapon. With respect to the degree of detail of technical analysis, the assessment is limited to a scoping level with the intent of separating problems from non-problems.

Section 2 of this report addresses the subject of water contamination threat characterization. It discusses water sources, contamination sources, and the water contamination processes; a model used to determine the time-dependent concentration of fission product radionuclides dissolved in water is presented. The subject of water contamination threat recognition is addressed in Section 3. The ability to measure radiological water contamination in order to satisfy specified water quality requirements is discussed. Water contamination threat countermeasures are discussed in Section 4 of this report. The effectiveness of water purification equipment and procedures are addressed. Section 5 of this report summarizes the conclusions that were reached during this assessment. Materials cited as reference within the report are identified in Section 6. Supporting material is provided in two appendices: Appendix A is a report on the water sources and characteristics within the geographic area selected for study; Appendix B is a report that documents the water contamination model developed for this assessment.

SECTION 2

THREAT CHARACTERIZATION

2.1 Introduction

Threat characterization refers to a determination of the magnitude and duration of the radiological water contamination that results from a specific set of circumstances and is expressed in terms of the time-dependent activity concentration of radionuclides in water. For a given contamination source and water source, the radiological water contamination is determined by considering the dissolution, mixing, and transport processes that affect the contaminant material. A simplified computer model has been developed to characterize the water contamination of rivers and streams by the fission products produced by a nuclear weapon.

2.2 Contamination Sources

Within the broad concept of nuclear warfare, three general types of radiological contamination sources can be considered: nuclear weapons, radiological warfare agents, and nuclear sabotage or terrorist actions. Although all three sources were initially considered, this assessment quickly focused on the nuclear weapon contamination source as the most significant and relevant to the overall objective of the assessment.

A nuclear weapon employed in the surface burst mode, either intentionally or accidently due to a firing system error or failure, can produce radioactive fallout over a widespread area. The intensity and extent of the fallout area is principally determined by the fission yield of the weapon and the meteorological conditions that

occur during the fallout deposition period.* An idealized fallout pattern (see Figure 1), based on the parameters given in "The Effects of Nuclear Weapons," provides a convenient way of portraying a fallout area.[1]** Table 1 shows some of the characteristics of idealized fallout patterns. Note that a 10-KT nuclear weapon can contaminate an area of approximately 9000 Km^2 with a reference dose rate equal to, or exceeding, 1 R/Hr at H+1 hour. Clearly, a nuclear weapon has the potential for contaminating a large area that encompasses hundreds of individual watersheds that could service U. S. Army water supply points.***

Radiological warfare was discussed in the popular press in the 1950's and the 1960's. One concept involved using special materials within a nuclear weapon to increase the amount of radioactive material produced. Another concept involved the localized dispersal or emplacement of gross fission products or selected radionuclides. Although scientifically feasible, such concepts have considerable engineering and logistical difficulties; in addition, the military utility of these concepts is not clear, nor is it clear how the concepts would fit within a nuclear warfare strategy that emphasizes the offense. Furthermore, based on discussions with representatives of the Defense Intelligence Agency, it was learned that no specific or credible radiological warfare threat is currently projected.[2] Therefore, no further consideration was given to the use of radiological warfare agents as a possible water contamination source.

* In general, tactical or low-yield nuclear weapons generate their yield by the fission process; strategic or high-yield nuclear weapons use both the fission and the fusion processes. If part of the weapon yield is obtained from the fusion process, the fallout area will be affected since the fusion process does not produce radioactive material to the extent that the fission process does.

** The number in the parentheses denotes a reference that is identified in Section 6.

***Typically, watersheds in the European area considered in this assessment had areas in the range of 10 Km to 50 Km .

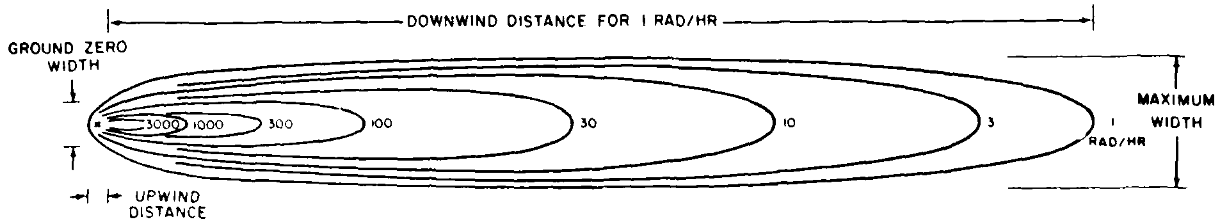


Figure 9.93. Illustration of idealized unit-time dose-rate pattern for early fallout from a surface burst. (The contour dimensions are indicated for a dose rate of 1 rad/hr.)

Table 9.93

SCALING RELATIONSHIPS FOR UNIT-TIME REFERENCE DOSE-RATE CONTOURS FOR A CONTACT SURFACE BURST WITH A YIELD OF W KILOTONS AND A 15 MPH WIND

Reference dose rate (rads/hr)	Downwind distance (statute miles)	Maximum width (statute miles)	Ground zero width (statute miles)
3,000	0.95 $W^{0.45}$	0.0076 $W^{0.86}$	0.026 $W^{0.58}$
1,000	1.8 $W^{0.45}$	0.036 $W^{0.76}$	0.060 $W^{0.53}$
300	4.5 $W^{0.45}$	0.13 $W^{0.66}$	0.20 $W^{0.48}$
100	8.9 $W^{0.45}$	0.38 $W^{0.60}$	0.39 $W^{0.42}$
30	16 $W^{0.45}$	0.76 $W^{0.56}$	0.53 $W^{0.41}$
10	24 $W^{0.45}$	1.4 $W^{0.51}$	0.68 $W^{0.4}$
3	30 $W^{0.45}$	2.2 $W^{0.50}$	0.89 $W^{0.41}$
1	40 $W^{0.45}$	3.3 $W^{0.48}$	1.5 $W^{0.4}$

Figure 1. Idealized fallout pattern parameters

Table 1. Characteristics of idealized fallout patterns

Downwind Distance to
Specified Reference Dose Rate (RDR) Limits
(Km)

Reference Dose Rate (RDR) Limits (R/HR at H+1 HR)	Weapon Yield (KT) 1	3	10	30	100	300	1000
RDR ≥ 1000	3	5	9	13	23	38	65
RDR ≥ 100	14	23	39	65	110	180	310
RDR ≥ 30	26	43	73	120	210	340	530
RDR ≥ 10	39	64	110	180	310	510	870
RDR ≥ 3	48	79	140	220	380	630	1100
RDR ≥ 1	64	100	180	300	510	830	1400

Total Area Within
Specified Reference Dose Rate (RDR) Limits
(Km^2)

Reference Dose Rate (RDR) Limits (R/HR at H+1 HR)	Weapon Yield (KT) 1	3	10	30	100	300	1000
RDR ≥ 1000	<1	2	9	33	140	530	2300
RDR ≥ 100	27	85	300	950	3400	11000	38000
RDR ≥ 30	98	300	1000	3300	10000	31000	105000
RDR ≥ 10	280	830	2700	7900	26000	75000	250000
RDR ≥ 3	530	1500	4700	13000	42000	120000	370000
RDR ≥ 1	1100	3000	9100	25000	77000	210000	660000

Percent of Area Within
Specified Reference Dose Rate (RDR) Bounds
(%)

Reference Dose Rate (RDR) Bounds (R/HR at H+1 HR)	Weapon Yield (KT) 1	3	10	30	100	300	1000
RDR ≥ 1000	<1	<1	<1	<1	<1	<1	<1
1000 > RDR ≥ 100	2	3	3	4	4	5	5
100 > RDR ≥ 30	7	7	8	8	9	10	10
30 > RDR ≥ 10	17	17	18	19	19	20	21
10 > RDR ≥ 3	24	24	23	23	22	21	21
3 > RDR ≥ 1	50	49	48	47	45	44	43

*These characteristics are based on the fallout pattern parameters given in Glasstone, S. and P. J. Dolan, "The Effects of Nuclear Weapons", U. S. Departments of Defense and Energy, Washington, D. C., 1977, page 430.

Nuclear sabotage or terrorist action has been the subject of much discussion for the past several years. Studies of postulated accidents at nuclear facilities tend to focus on groundwater contamination rather than surface water contamination; the resulting level of water contamination and the time scale on which the contamination occurs indicate that such events are long term environmental problems rather than problems of concern in a nuclear warfare environment.(3) Conceivably, material stolen from a nuclear facility could be used to cause the contamination of a water supply source, for example, a spent reactor fuel assembly, stolen from a power plant or during shipment, could be dumped into a water reservoir or lake. The potential level of water contamination associated with such an event could be rather high, on the order of 300,000 pCi/ℓ (gross fission products);* however, the extent of the water contamination could be quite localized. Since nuclear weapons have the potential for equally severe levels of water contamination over wide scale areas,** there appeared to be no particular benefit to any further study of hypothetical nuclear sabotage or terrorist actions.

2.3 Water Sources

In general, the variety of raw water sources includes springs and wells, rivers and stream, lakes and ponds, and ocean bays and harbors. However, within the context of nuclear warfare in Europe, the imposition of strict radiological defense measures will limit the selection of raw water sources to those sources that have sufficient

* A spent fuel assembly contains roughly 600,000 Ci of gross fission products after a cooling time of one year.(4) It is estimated that 0.1% of the fission products would be released into the water (see Reference 5). A small reservoir or lake having an average depth of 10 ft. and a water surface area of 0.25 mi^2 contains 2×10^9 ℓ of water.

**In Section 2.5, a model is presented that correlates the level of water contamination with the level of fallout contamination. For a fallout level of 1 R/Hr at H+1 hour, the water contamination is initially around 10^8 pCi/ℓ and drops to about 10^5 pCi/ℓ in about 10 days.

capacity to support the operation of an engineer water supply point. In addition, only those raw water sources that are locally available to the field forces are of interest.

For this water contamination threat assessment, the focus was on a preselected nuclear warfare scenario area in West Germany bounded by Marburg, Giessen, and Frankfurt am Main on the west, and the Fulda River Valley on the east (See Figure 2). Descriptive information on the water source characteristics of this area are contained in Appendix A.

Within the scenario area, the primary raw water sources are rivers and streams. Based on a map study (scale 1:50000) of the area and in accordance with U. S. Army Engineer School doctrine, thirty water supply points were identified and the specific watershed area for each water supply point was delineated. The area of the watersheds ranged from 8 Km^2 to 60 Km^2, with an average value of 20 Km^2. For a typical watershed, the stream or river area was about 0.1% of the total watershed area and the estimated average stream velocity at the watershed exit was 0.6 m/s. In the absence of precipitation runoff, the typical volumetric flow rate ranged from 38 ℓ/s (36,000 gph) to 100 ℓ/s (95,000 gph), with the lower flow rate occurring in July, August, and September and the higher flow rate occurring in February, March and April.

Precipitation occurs frequently (on almost half the days) within the scenario area with the largest amounts of rainfall typically occurring in June, July, and August. When rainfall sufficient to promote surface runoff occurs, the volume of water associated with the precipitation runoff can be a factor of 2 to 5 times more than the volume of water present on the watershed during dry conditions. This volume of surface runoff water will flow off the watershed into the stream or river over a period of four days.

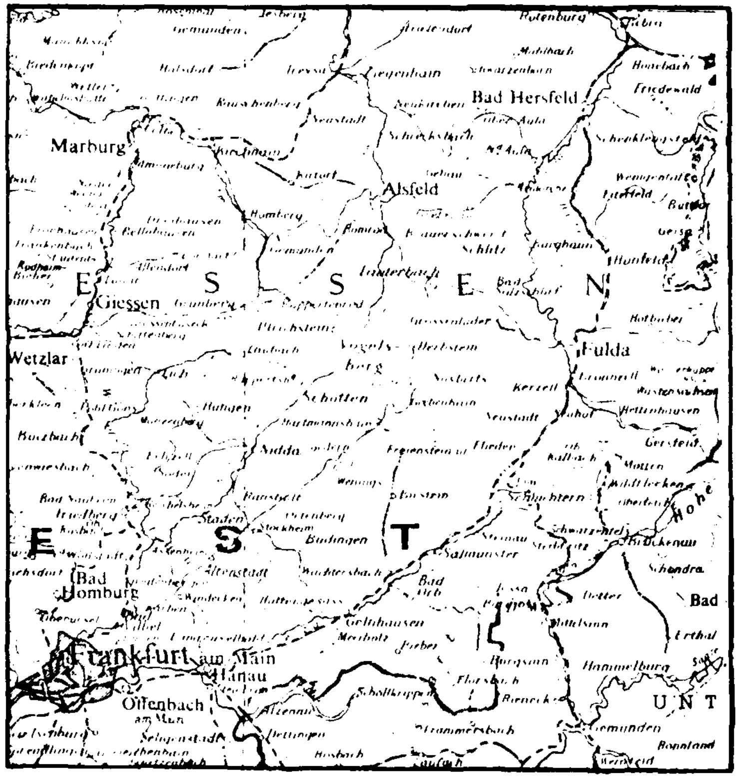


Figure 2. Scenario area

2.4 Water Contamination Processes

The radiological contamination of rivers and streams that would occur due to the radioactive fallout from a nuclear weapon detonation is the result of several different processes. Fallout material is produced, transported by the winds, and then deposited on the watershed area. The fallout material that is deposited on the water surface will experience dissolution, mixing, and transport, along with radioactive decay. The fallout material that is deposited on the land surface will initially experience only radioactive decay, but subsequent precipitation could dissolve the material and transport it to the watershed stream or river where it mixes with the channel water and is transported out of the watershed area.

The processes that must be considered to determine the radiological water contamination thus include:

- fallout production, transport, and deposition,
- radioactive decay,
- dissolution of radionuclides in fallout material,
- transport of radionuclides by precipitation runoff, and
- aquatic mixing and transport.

These water contamination processes, with the exception of the fallout production, transport, and deposition process, have been incorporated into a simplified computer model developed for this assessment. A detailed description of the water contamination model is provided in Appendix B.

The following material provides a discussion of the water contamination processes identified above, with emphasis on the approach used to incorporate the processes into the model. It should be noted that this water contamination model addresses the water concentration of soluble radioactive material; insoluble radioactive material is not considered since such material can be easily removed from the water by simple filtration methods.

2.4.1 Fallout Production, Transport, and Deposition

The process of fallout production, transport, and deposition determines the initial surface contamination of the watershed. Typically, the output of a fallout model specifies the unit-time reference dose rate (e.g., 10 R/Hr at H+1 hour) within the fallout field. For the purposes of the water contamination model, it is necessary to know the specific radionuclide ground concentrations (e.g., Ci/Km^2 at H+1 hour for Sr-90) that correlate with the unit-time reference dose rate. Since the prime concern is with the radionuclide composition of the fallout, rather than the specific dimensional characteristics and orientation of the fallout pattern dose rate contours, it is appropriate to use idealized fallout patterns, like those discussed in Section 2.2 and Reference 1, to determine unit-time reference dose rates and then employ a separate procedure to convert the dose rates to radionuclide ground concentrations.*

A methodology to correlate radionuclide ground concentrations with fallout radiation dose rates, recently developed by SAI for use on DNA's Nuclear Test Personnel Review (NTPR) program is contained in a computer code named FIIDOS.[7] The radionuclide inventory and associated gamma radiation emission spectrum are determined for a mixture of fallout material that includes fractionated fission products, light elements which were made radioactive by neutron capture or activation, and heavy elements or actinides which were part of the nuclear weapon or resulted from neutron capture by weapon

*Initially, consideration was given to the use of the DELFIC fallout code (Reference 6) to calculate radionuclide ground concentrations directly. However, since DELFIC outputs mass chain depositions rather than specific radionuclide depositions, the code would have required modifications. In addition, the use of a sophisticated fallout code like DELFIC could have obscured the important relationship between radionuclide ground concentrations and fallout dose rate contours by focusing too much attention on the mechanics of the fallout process and the details of the fallout pattern.

material. By using gamma radiation exposure factors to determine the above-ground dose rate that results from the calculated gamma radiation emission spectrum in a planar source geometry, the relationship between the dose rate and the surface-distributed radionuclide inventory is established. It should be noted that to use FIIDOS the user must provide fallout material characterization data to treat the fractionation of fission products and weapon test data to specify the inventory of activated light elements and actinides.

The fallout radiation dose rate-radionuclide ground concentration correlation developed for this assessment is based on a source consisting of unfractionated U-235 fission products. It is recognized that because of fission product fractionation the composition of the fission product material within a fallout field is not uniform and the relative abundance of a radionuclide in a fallout field is not the same as that observed in laboratory experiments or calculated by basic fission product buildup and depletion computer codes. However, the inclusion of fractionation effects would represent an added complexity that is not necessary, or appropriate, for the purposes of this assessment and could impact the results of the assessment in a non-conservative manner by causing some important elements (e.g., iodine and strontium) to be partially depleted from the radionuclide inventory. The source term used for the correlation does not include activated light elements or actinides; although such radionuclides generally account for less than 10% of the radioactivity in the fallout material, there are some radionuclides (e.g., isotopes of plutonium) that could possibly be of significance to radiological dose estimates. However, the inclusion of such elements in the source term would require gross assumptions about nuclear weapon design or access to classified design and intelligence information.

Table 2 lists the radionuclide ground concentrations (Ci/Km^2 at H+1 hour) for a mixture of unfractionated U-235 fission products that is referenced to a fallout deposition contour that has an above-ground external radiation exposure rate of 1 R/Hr at H+1 hour. For completeness, the table includes all the radionuclides, with the

Table 2. Radionuclide ground concentrations

Radionuclide	Activity (Ci/km²)	Radionuclide	Activity (Ci/km²)	Radionuclide	Activity (Ci/km²)
H-3	2.[illegible]5 - 04	Rb-86	2.40 - 04	Nb-99	2.13 - 04
Zn-72	6.04 - 03	Rb-86m	5.71 - 18	Mo-99	1.04 + 02
Zn-74	8.56 - 10	Rb-87	2.96 - 12	Mo-101	1.60 + 03
Ga-72	3.01 - 04	Rb-88	1.19 + 03	Mo-102	7.23 + 02
Ga-73	2.09 - 01	Rb-89	1.77 + 03	Mo-103	2.59 - 13
Ga-74	1.57 - 01	Rb-90	2.11 - 01	Mo-104	5.25 - 07
Ga-75	5.[illegible] - 08	Rb-90m	1.27 - 00	Mo-105	7.51 - 16
Ge-73m	2.09 - 01	Rb-91	9.63 - 14	Tc-99	7.35 - 09
Ge-75	2.14 - 00	Sr-87m	2.56 - 04	Tc-99m	9.70 - 00
Ge-75m	3.52 - 09	Sr-89	4.06 - 00	Tc-101	4.48 + 03
Ge-77	7.56 - 01	Sr-90	2.73 - 02	Tc-102	7.30 + 02
Ge-77m	2.22 - 17	Sr-91	6.65 + 02	Tc-102m	1.55 - 03
Ge-78	2.50 + 01	Sr-92	1.98 + 03	Tc-103	1.55 - 12
Ge-79	4.22 - 22	Sr-93	2.30 + 02	Tc-104	1.01 + 03
As-76	1.66 - 05	Sr-94	1.60 - 09	Tc-105	6.27 + 01
As-77	4.76 - 01	Y-90	5.69 - 03	Tc-109	1.32 - 18
As-78	1.16 - 01	Y-90m	3.22 - 03	Ru-103	4.20 - 00
As-79	5.74 - 0[illegible]	Y-91	2.05 - 01	Ru-105	2.66 + 02
Se-77m	[illegible].43 - 03	Y-91m	2.[illegible]1 + 02	Ru-106	7.88 - 02
Se-79	1.[illegible] - [illegible]	Y-92	4.06 + 02	Ru-107	3.75 - 01
Se-79m	1.01 + 01	Y-93	6.83 + 02	Ru-108	3.[illegible]1 - 01
Se-81	1.[illegible] + 0[illegible]	Y-94	2.85 + 03	Ru-109	4.38 - 18
Se-81m	1.33 - 00	Y-95	8.68 + 02	Rh-103m	2.12 - 00
Se-83	1.1[illegible] + 02	Y-96	2.66 - 03	Rh-104	8.37 - 08
Se-83m	8.4[illegible] - 12	Zr-90m	1.29 - 05	Rh-104m	7.04 - 08
Se-84	7.44 - 02	Zr-93	4.93 - 08	Rh-105	5.74 - 00
Se-85	1.[illegible]8 - 23	Zr-95	4.[illegible] - 00	Rh-105m	6.88 + 01
Br-80	6.55 - 05	Zr-97	4.[illegible] + 02	Rh-106	7.88 - 02
Br-80m	2.61 - 05	Nb-93m	6.6[illegible] - 11	Rh-106m	1.77 - 04
Br-82	5.[illegible] - 03	Nb-94	4.[illegible] - 12	Rh-107	2.36 + 02
Br-82m	1.[illegible] - 03	Nb-94m	4.69 - 06	Rh-108	3.54 - 01
Br-83	2.14 + 02	Nb-95	2.9[illegible] - 03	Rh-108m	6.20 - 04
Br-84	6.95 + 0[illegible]	Nb-95m	5.0[illegible] - 04	Rh-109	2.52 - 08
Br-84m	1.99 - 01	Nb-96	2.[illegible]1 - 02	Rh-109m	1.03 - [illegible]
Br-85	2.02 - 02	Nb-97	2.20 + 02	Rh-111	2.43 - 14
Br-86	1.91 - 15	Nb-97m	3.50 + 02	Pd-107	6.53 - 09
Br-87	6.65 - 15	Nb-98m	3.73 + 03	Pd-109	1.13 + 01

Table 2. Radionuclide ground concentrations (cont'd)

Radionuclide	Activity (Ci/Km²)	Radionuclide	Activity (Ci/Km²)	Radionuclide	Activity (Ci/Km²)
Pd-109m	3.01 - 01	In-120m	7.28 - 19	Te-125m	3.19 - 07
Pd-111	2.36 + 01	In-121m	5.57 - 04	Te-127	1.09 - 01
Pd-111m	8.26 - 02	In-123m	3.73 - 20	Te-127m	9.89 - 05
Pd-112	2.21 - 00	Sn-119m	9.77 - 05	Te-129	9.07 + 01
Pd-113	1.52 - 09	Sn-121	1.56 - 00	Te-129m	7.02 - 02
Pd-114	3.01 - 05	Sn-121m	4.17 - 08	Te-131	2.61 + 03
Ag-109m	1.13 + 01	Sn-123	9.14 - 03	Te-131m	1.31 + 01
Ag-110	2.01 - 09	Sn-123m	1.52 + 01	Te-132	7.11 + 01
Ag-111	2.50 - 01	Sn-125	1.01 - 01	Te-133	1.18 + 03
Ag-111m	2.45 + 01	Sn-125m	5.64 - 00	Te-133m	1.24 + 03
Ag-112	4.48 - 01	Sn-126	1.98 - 07	Te-134	4.08 + 03
Ag-113	6.13 - 00	Sn-127	8.47 + 01	I-128	8.42 - 04
Ag-113m	5.69 - 10	Sn-127m	7.00 - 02	I-129	2.71 - 10
Ag-114	3.10 - 05	Sn-128	3.64 + 02	I-130	6.55 - 03
Ag-115	1.76 + 01	Sn-129	1.30 + 01	I-130m	2.92 - 03
Ag-116	9.44 - 05	Sn-129m	5.99 - 04	I-131	9.54 - 00
Ag-117	1.52 - 12	Sn-130	3.43 - 01	I-132	3.03 + 01
Cd-111m	2.96 - 08	Sn-131	5.78 - 13	I-133	3.03 + 02
Cd-113m	1.90 - 06	Sn-132	5.99 - 23	I-134	4.36 + 03
Cd-115	5.18 - 01	Sb-122	2.33 - 06	I-134m	1.20 - 01
Cd-115m	4.34 - 03	Sb-122m	5.71 - 09	I-135	9.86 + 02
Cd-117	7.07 - 00	Sb-124	1.11 - 05	I-136	1.84 - 08
Cd-117m	3.08 - 00	Sb-124m	1.54 - 12	I-136m	4.[illegible] - 12
Cd-118	2.18 + 01	Sb-125	2.89 - 03	Cs-134	1.49 - 06
Cd-119	1.57 - 00	Sb-126	2.87 - 03	Cs-134m	6.02 - 03
Cd-119m	8.[illegible] - 04	Sb-126m	2.62 - 01	Cs-135	2.38 - 09
Cd-121	1.37 - 1[illegible]	Sb-127	2.16 - 01	Cs-135m	2.87 - 01
In-114	[illegible] - 11	Sb-128	5.71 - 09	Cs-136	6.09 - 02
In-114m	3.[illegible] - 11	Sb-128m	4.31 + 02	Cs-137	[illegible] - 02
In-115m	5.48 - 02	Sb-129	2.45 + 02	Cs-138	5.53 + 03
In-116m	2.41 - 05	Sb-130	1.16 + 01	Cs-138m	3.19 - 03
In-117	1.76 - 00	Sb-130m	1.02 + 03	Cs-139	5.92 + 02
In-117m	2.64 - 00	Sb-131	1.53 + 03	Cs-140	4.48 - 12
In-118	2.28 + 01	Sb-132	1.92 - 04	Ba-135m	6.81 - 06
In-119	9.40 - 01	Sb-132m	8.51 - 01	Ba-136m	9.72 - 03
In-119m	1.66 + 01	Sb-133	2.07 - 03	Ba-137m	2.68 - 02
In-120	1.62 - 17	Te-123m	5.06 - 11	Ba-139	3.71 + 03

Table 2. Radionuclide ground concentrations (cont'd)

Radionuclide	Activity (Ci/Km^2)	Radionuclide	Activity (Ci/Km^2)	Radionuclide	Activity (Ci/Km^2)
Ba-140	2.36 + 01	Pm-149	5.20 - 04	Tb-162m	6.18 - 04
Ba-141	2.50 + 03	Pm-150	7.95 - 02	Tb-163	1.36 - 03
Ba-142	7.53 + 02	Pm-151	5.83 - 02	Tb-164	8.93 - 08
La-138	2.47 - 17	Pm-152	2.43 - 03	Dy-165	5.76 - 05
La-140	6.32 - 01	Pm-152m	1.32 - 01	Dy-165m	3.61 - 17
La-141	1.49 + 03	Pm-153	1.19 - 01	Dy-166	1.15 - 05
La-142	3.01 + 03	Pm-154	9.84 - 05	Ho-166	1.40 - 07
La-143	1.54 + 03	Pm-154m	3.99 - 08	Ho-166m	3.66 - 13
La-144	6.02 - 22	Pm-157	5.39 - 14		
Ce-141	9.33 - 01	Sm-151	3.26 - 09		
Ce-142	2.05 - 12	Sm-153	9.61 - 03		
Ce-143	1.95 + 02	Sm-155	2.33 - 00		
Ce-144	9.42 - 01	Sm-156	7.02 - 01		
Ce-145	3.29 - 01	Sm-157	3.61 - 01		
Ce-146	7.98 + 02	Sm-158	3.61 - 00		
Ce-147	5.18 - 11	Sm-159	1.17 - 05		
Ce-148	9.82 - 21	Sm-160	9.65 - 03		
Pr-142	2.08 - 06	Eu-152	2.96 - 11		
Pr-142m	5.04 - 06	Eu-152m	3.36 - 07		
Pr-143	2.98 - 01	Eu-154	2.87 - 08		
Pr-144	9.33 - 01	Eu-155	7.18 - 07		
Pr-144m	1.20 - 02	Eu-156	2.59 - 04		
Pr-145	6.86 + 02	Eu-157	2.03 - 02		
Pr-146	2.66 + 03	Eu-158	3.78 - 01		
Pr-147	5.01 + 02	Eu-159	2.73 - 01		
Pr-148	8.61 - 05	Eu-160	1.39 - 20		
Pr-149	4.80 - 04	Eu-162	2.18 - 04		
Nd-147	1.05 + 01	Gd-153	1.63 - 12		
Nd-149	5.22 + 02	Gd-159	2.16 - 03		
Nd-151	8.98 + 01	Gd-161	1.67 - 05		
Nd-152	4.99 + 01	Gd-162	1.24 - 02		
Nd-153	1.08 - 12	Gd-163	3.71 - 12		
Nd-154	4.29 - 01	Gd-164	8.72 - 03		
Nd-156	1.14 - 16	Gd-165	3.73 - 12		
Pm-147	9.84 - 08	Tb-160	1.07 - 08		
Pm-148	5.34 - 06	Tb-161	4.59 - 06		
Pm-148m	6.97 - 07	Tb-162	5.76 - 05		

exception of the isotopes of the noble gas krypton and xenon, that are present after a decay time of one hour.

It is not necessary to consider all the radionuclides listed in Table 2 to adequately characterize radiological water contamination. The most significant radionuclides have been identified by a screening process that considered the relative contribution of each radionuclide to potential ingestion doses.* Based on unfractionated, U-235 time-dependent fission product inventories obtained from FIIDOS and a 50-year, ingestion dose conversion factors obtained from ORNL/NUREG/TM-190,[8] the percent of the total dose commitment to specific body organs has been calculated for each radionuclide. The results of such calculations are shown in Table 3 where those radionuclides that contribute more than 1% to the organ doses are identified. Clearly, a host of radionuclides could be significant to the ingestion dose from contaminated water and the relative importance of specific radionuclides is both time and organ dependent.

For the radionuclide screening process described above, the focus was on the internal dose associated with the ingestion of radiologically contaminated water. Similar calculations, using dose rate conversion factors for external exposure,[9] have been used to determine the significance of radionuclides to the external dose rate associated with immersion in radiologically contaminated water. The external exposure pathway is not of concern to this assessment; however, the external dose rate does provide an indication of the radiation dose rate that might be measured by radiation instruments. Table 4 shows the results of the external exposure calculations for both beta and gamma radiation.

*It is recognized that fission product fractionation during fallout formation and the effects of solubility during the contamination process will affect the radionuclide composition of the fission product debris in water. It is also noted that the use of 50-year, dose conversion factors might not be appropriate for addressing wartime doses. Nevertheless, this approach is still adequate as a screening process for the identification of important radionuclides.

Table 3. Percent of organ dose commitment for specific radionuclides*.

Organ - Bone

Radionuclide	Decay Time H+1	H+6	H+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+10
[illegible]	[illegible]	[illegible]	9	12	15	18	21	29	45	13	1	
[illegible]	3	4	5	6	[illegible]	11	12	17	37	79	92	94
[illegible]	11	11	[illegible]	4	1							
[illegible]												
[illegible]												
Zr-95						1	1	1	1	1		
Zr-97	6	7	7	5	3	1	1					
Nb-95									1	1		
Nb-97	1	3	3	2	1							
Mo-99	[illegible]	26	[illegible]	[illegible]	33	32	[illegible]	19				
Ru-103							1	1	1			
Ru-105	1	1										
Ru-106									1	1	1	
Rh-105												
[illegible]												
[illegible]												
[illegible]												
[illegible]	1											
[illegible]	1	1	1	1	1							
[illegible]	9	11	14	16	17	17	16	12				
[illegible]		1	1	1	[illegible]	2	2	2	1			
[illegible]		1	1	1	1	1	1	1				
[illegible]	4	[illegible]	[illegible]	5	[illegible]	[illegible]	1					
[illegible]	19	[illegible]										
[illegible]	17	11	7	2								
[illegible]					1	1	1	1	2	5	5	6
[illegible]												
[illegible]	[illegible]	4	[illegible]	[illegible]	[illegible]	9	10	12	7			
[illegible]				1	1	[illegible]	[illegible]	3	[illegible]			
[illegible]												
[illegible]	1	1	[illegible]	1	1	1	1					
[illegible]												
[illegible]												
[illegible]												

*Organ dose commitments were calculated for a mixture of unfractionated U-235 fission products based on 50-year ingestion dose conversion factors. Calculations were performed for specific decay times: H-hours, D-days, M-months, Y-years. Totals might not give 100 due to rounding.

Table 3. Percent of organ dose commitment for specific radionuclides (cont).

Organ - Lower Large Intestine-Wall

Radionuclide	Decay Time											
	H+1	H+6	H+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+10
Sr-89	1	1	1	1	2	3	4	5	11	11	2	
Sr-90										1	2	34
Sr-91	20	16	13	8	2	1						
Y-90										1	2	53
Y-91			1	2	3	5	6	8	16	20	6	
Zr-95				1	1	1	1	2	4	6	2	
Zr-97	49	48	46	40	25	13	6					
Nb-95									1	6	2	
Nb-97												
Mo-99	1	1	1		1	1	1	1				
Ru-103					1	1	1	1	2	1		
Ru-105	3	1	1									
Ru-106									1	5	8	
Rh-105		1	1	1	2	1	1					
Sb-127		1	1	1	1	2	2	1				
Te-127m												
Te-129m									1			
Te-131												
Te-131m	1	1	1	1	1	1	1					
Te-132	4	4	5	6	9	10	10	7				
I-131												
I-132												
I-133												
I-134												
I-135												
Cs-137										1	12	
Ba-137m												
Ba-140	4	5	6	9	14	18	21	25	19			
La-140			1	2	5	9	12	17	15			
Ce-141			1	1	2	3	3	4	6	2		
Ce-143	15	17	19	21	21	18	13	4				
Ce-144		1	1	1	2	2	3	4	9	47	74	1
Pr-143			1	2	4	7	10	13	12			
Nd-147	1	1	1	2	3	4	4	5	3			

Table 3. Percent of organ dose commitment for specific radionuclides (cont).

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]										[illegible]	1	
[illegible]										[illegible]	7	8
[illegible]												
[illegible]												
[illegible]												
[illegible]												
Zr-97												
[illegible]										[illegible]		
[illegible]												
[illegible]												
[illegible]										1		
[illegible]												
[illegible]										[illegible]	[illegible]	
[illegible]												
[illegible]												
[illegible]										1		
[illegible]										[illegible]		
[illegible]	[illegible]											
[illegible]		1	1	1	[illegible]	[illegible]						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
[illegible]	[illegible]	[illegible]										
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]							
[illegible]										[illegible]	[illegible]	[illegible]
[illegible]												
[illegible]												
[illegible]												
[illegible]												
[illegible]												
[illegible]												
[illegible]												
Nd-147												

Table 3. Percent of organ dose commitment for specific radionuclides (cont).

Organ - Total body

	Decay Time											
Radionuclide	0+1	0+6	6+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+10
Sr-89	1	1	1	1	2	3	4	6	17	17	1	
Sr-90					1	1	1	2	[illegible]	3	[illegible]	64
Sr-91	15	16	13	8	2	1						
Y-90												
Y-91					1	1	1	2	5	4	1	
Zr-95					1	1	1	2	5	6	1	
Zr-97	23	24	24	21	13	6	3					
Nb-95									3	[illegible]	[illegible]	
Nb-97		1	1	1	1							
Mo-99	9	12	14	18	22	23	23	17				
Ru-103					1	1	1	2	4	1		
Ru-105	2	2	1									
Ru-106									1	5	5	
Rh-105				1	1							
Sb-127					1	1	1	1				
Te-127m												
Te-129m									1			
Te-131	2											
Te-131m	1	1	1	1	1	1	1					
Te-132	8	10	13	16	21	23	24	20	1			
I-131	1	2	2	3	4	6	7	6	4			
I-132		1	1	1	2	2	2	2				
I-133	6	8	9	8	6	4	2					
I-134	15	1										
I-135	12	10	7	3								
Cs-137						1	1	1	4	20	28	35
Ba-137m												
Ba-140	2	3	3	5	7	9	11	14	16			
La-140			1	2	4	6	9	14	16			
Ce-141						1	1	1	3			
Ce-143	4	6	6	7	7	6	4	1				
Ce-144								1	3	9	8	
Pr-143					1	1	2	3	3			
Nd-147				1	1	1	1	2	1			

Table 4. Percent of external dose rate for specific radionuclides*.

Radionuclide	Beta Radiation: Decay Time H+1	H+6	H+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+10
Br-84	2											
Rb-88	7	15	8	1								
Rb-89	5											
Sr-89					1	2	2	4	13	14	3	
Sr-90											1	14
Sr-91	1	6	8	10	5	2						
Sr-92	1	2	1									
Y-90										2	4	67
Y-91m												
Y-91					1	2	3	4	15	20	6	
Y-92	2	21	25	10								
Y-93	2	11	16	20	12	4	1					
Zr-95							1	1	3	5	2	
Zr-97	1	4	8	13	15	10	[illegible]	[illegible]				

Radionuclide	Gamma Radiation: Decay Time H+1	H+6	H+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+
Br-84	2											
Rb-88	1	5	3									
Rb-89	6											
Sr-89												
Sr-90												
Sr-91	1	6	10	9	4	1						
Sr-92	4	14	8	1								
Y-90												
Y-91m		3	5	5	2	1						
Y-91												
Y-92		4	5	2								
Y-93		1	1	1	1							
Zr-95					1	1	2	3	13	32	27	
Zr-97		1	2	3	3	2	1					

*External dose rates were calculated for a mixture of unfractionated U-235 fission products based on immersion in radiologically contaminated water. Calculations were performed for specific decay times: H-hours, D-days, M-months, Y-years. Totals might not give 100 due to rounding.

Table 4. Percent of external dose rate for specific radionuclides (cont).

Radionuclide	Beta Radiation — Decay Time											
	H+1	H+6	H+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+10
Nb-95												
Nb-97m												
Nb-97		3	5	[illegible]	10	7	4					
Mo-99		1	2	4	9	13	15	13				
Tc-99m						1	1	1				
Tc-101	6											
Ru-103								1	1	1		
Pu-105			1	1								
Rh-103m									1			
Rh-105				1	1	1	1	1				
Rh-106									1	5	8	
Sb-125												
Sb-127						1	1	1				
Te-127								1				
Te-129		1	1						1			
Te-131m												
Te-131	5											
Te-132				1	2	3	3	3				
Te-133m	2											
Te-133	3											
Te-134	3											

Radionuclide	Gamma Radiation — Decay Time											
	H+1	H+6	H+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+10
Nb-95									7	58	57	
Nb-97m		4	8	11	9	6	3					
Nb-97		4	9	12	10	6	3					
Mo-99			1	1	3	3	3	3				
Tc-99m				1	2	2	3	2				
Tc-101	3											
Ru-103					1	1	1	2	6	5	1	
Pu-105		2	2	1								
Rh-103m												
Rh-105												
Rh-106										1	3	
Sb-125												1
Sb-127					1	1	1	1				
Te-127												
Te-129												
Te-131m			1	1	2	2	1					
Te-131	2											
Te-132			1	2	3	4	4	4				
Te-133m	5	1										
Te-133	[illegible]											
Te-134	6	1										

Table 4. Percent of external dose rate for specific radionuclides (cont).

Radionuclide	Beta Radiation												Gamma Radiation											
	Decay Time												Decay Time											
	H+1	H+6	H+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+10	H+1	H+6	H+12	D+1	D+2	D+3	D+4	D+7	M+1	M+6	Y+1	Y+10
I-131					1	1	3	4	2							1	2	2	3	4	3			
I-132		1	1	4	9	13	16	15						2	7	15	28	37	40	36	1			
I-133		2	4	9	11	10	6	1						3	7	12	12	9	5	1				
I-134	7	3											20	13										
I-135	1	4	5	4	1								3	17	23	15	3							
Cs-137											1	13	23	1										
Cs-138	19																							
Cs-139	3																							
Ba-137m												5										1	5	99
Ba-139	9	5	1																					
Ba-140				1	2	4	6	10	11								1	1	2	2	4			
Ba-141	6												4											
Ba-142	1												1											
La-140				1	3	6	9	17	21						1	2	7	15	22	38	62			
La-141	4	12	9	3										1	1									
La-142	7	5	1										14	16	3									
Ce-141					1	1	1	3	6	2										1	2	1		
Ce-143		1	3	7	12	13	12	5						1	2	4	6	5	4	2				
Ce-144									1	3	5											1	3	
Pr-143					1	3	5	9	12															
Pr-144						1	1	2	8	44	69	1										1	4	
Nd-147					1	2	2	3	3									1	1	1	1			

2.4.2 Radioactive Decay

The process of radioactive decay is important to considering the time dependency of the radiological water contamination. Since radionuclides are typically part of a chain of isotopes connected by the process of radioactive decay, the decay of one radionuclide is frequently the source of another radionuclide.

In the water contamination computer model used for this assessment, radionuclides were treated as parent or daughter members of a two-member, radionuclide chain. Since some radionuclide decay chains contain more than two members, this approach sacrifices accuracy for modeling efficiency and simplicity. However, frequently only two members of the chain are radionuclides that are actually important to water contamination.

2.4.3 Dissolution of Radionuclides

The dissolution of radionuclides in fallout from the solid phase to the liquid phase is probably the most important water contamination process. The degree to which the radionuclides in fallout material are soluble or insoluble in water, and the rate at which the radionuclides dissolve are basic to the modeling of radiological water contamination. Unfortunately, the available information on the solubility and dissolution rates of radionuclides in fallout is quite limited.

Most of the statements found in the literature regarding fallout solubility refer to fallout as basically insoluble. The statements are typically based on measurements of fallout solubility in terms of the gross beta radiation activity before and after water washing of fallout particles collected during nuclear weapons tests. Generally, 1% to 3% of the gross beta activity is removed from the fallout material by such washings.[10,11,12]

There are very few references in the literature regarding the specific radionuclides in fallout that are soluble. A group of six radionuclides (i.e., Sr-89, Sr-90, Ru-106, I-131, Cs-137, and Ba-140) have been labeled as soluble in some water contamination studies.[13,14] However, no substantial discussion of the solubility of specific radionuclides in fallout has been found. Similarly, there are few references in the literature regarding the dissolution rates of radionuclides in fallout. Solubility rates for actual fallout particles are discussed by Larson[10] and some experiments with artificial fallout particles have been performed.[15] However, no substantial models, theories, or results have been found.

In the absence of the necessary fallout solubility data, the use of radionuclide-specific distribution coefficients provides a convenient and reasonable approach for fallout solubility modeling. The concept of the distribution coefficient, Kd, was originally developed from ion-exchange theory to represent the equilibrium distribution of a trace constituent between the solid exchanger and the solution. Currently, the distribution coefficient concept is being used to quantify the chemical interaction of radionuclides with soils and minerals for the assessment of the contamination of water bodies by releases from nuclear power plants and for the analysis of the impacts of potential releases of radioactive material from nuclear waste repository facilities.[16,17]

A distribution coefficient is defined as:

$$Kd = \frac{\text{amount of radionuclide sorbed on solid phase}}{\text{amount of radionuclide left in solution}}$$

Since the solid phase activity is usually expressed in units of Ci/g and the liquid phase activity in units of Ci/mℓ, Kd typically has units of mℓ/g. For a specific element, the value of Kd is dependent upon the chemical state of the element, the type of solid matrix in which it exists, the physical characteristics of the solid and liquid phases, and the nature of the dissolution process; however, the actual

relationship of the value of Kd to these parameters is generally not known. Values of Kd are normally determined by laboratory or field experiments and can exhibit a wide range; for example, the Kd value for Zr ranges from 1000 to 10000 m ℓ /g and the value for Sr ranges from 8 to 4000 m ℓ/g.

Table 5 shows selected values of distribution coefficients for those elements whose radioisotopes are considered in the water contamination model. As cautioned in Reference 16, it is a gross generalization to prescribe single-valued, non-specific distribution coefficients; although it is recognized that such parameters are needed by computer modelers for preliminary or scoping studies. Reference 16 suggests that median Kd values, like those shown in Table 5, should be considered to vary by a factor of 10 for those values greater than 100 m ℓ/g.

The distribution coefficient refers to the phase distribution of a radionuclide at equilibrium. For the fallout material deposited on the water surface, it is assumed that equilibrium is reached within a time period corresponding to the time constant of the mixing tank model of the watershed (see Section 2.4.5). For the fallout material deposited on the land surface, it is assumed that equilibrium is reached instantaneously and maintained for the four days that the runoff water remains on the watershed. These assumptions about the time to achieve equilibrium are, in effect, assumptions about the rate at which the radionuclides in the fallout dissolve. As pointed out above, there is no strong basis for supporting such assumptions; nevertheless, such assumptions are necessary in order to model the water contamination processes.

2.4.4 Transport of Radionuclides by Precipitation Runoff

The importance of precipitation runoff with respect to water contamination was not generally recognized until the late 1960's. Prior to that time, the focus had been on the pollution caused by

Table 5. Selected distribution coefficients*

Element	Kd (mℓ/g)
Ba	500
Ce	10,000
Cs	1,000
I	10
La	500
Mo	25
Nb	10,000
Nd	10,000
Pm	10,000
Pr	10,000
Rh	5,000
Ru	5,000
Sb	100
Sr	1,000
Tc	1
Te	100
Y	1,000
Zr	1,000

$$^{*}Kd = \frac{\text{amount of radionuclide sorbed on solid phase (Ci/g)}}{\text{amount of radionuclide left in solution (Ci/m}\ell\text{)}}$$

The above Kd values were taken from References 16 and 18 and represent mean or best-estimate values. Kd values greater than 100 mℓ/g should be considered to vary (±) by a factor of 10.

point sources as opposed to nonpoint sources Now, it is estimated that nonpoint sources of pollution account for more than half of the total water quality problems in the United States.[19]

Radiological water contamination by nonpoint sources has received little, if any, attention in the current literature on the environmental impacts of nuclear facilities, since such facilities correspond to point pollution sources. The principal source of radiological nonpoint pollution has been the atmospheric testing of nuclear weapons; however, with the cessation of such testing by the major nations, the subject has received little attention. Nevertheless, the environmental contamination of water supplies by fallout has been noted as a source of background radiation[20] and a possible concern in connection with the long-term impact of strategic nuclear warfare.[21]

The transport of radionuclides from the land surface into the local river or stream by precipitation runoff is an important water contamination process in this assessment. As pointed out in Section 2.3, and discussed further in Appendix A, within the selected nuclear warfare scenario area sufficient rainfall occurs with such frequency that precipitation runoff is a common occurrence. Furthermore, for a typical watershed area, the stream or river area is about 0.1% of the total watershed area, indicating that the land surface of the watershed area provides a large area source for potential water contamination.

The volume of surface runoff water that results from a given rain is determined by the area of the watershed, the amount of water deposited by the rain, and the prior precipitation history of the watershed. This volume of water flows off the land surface into the local water channel is a non-linear fashion that continues for about four days. The subject of precipitation runoff is discussed in various civil engineering texts, the specific approach used for this assessment is discussed in detail in Appendix A.

While the potential precipitation runoff water remains on the land surface, it effects a phase separation of the radionuclides present in the deposited fallout material. The radionuclides that are partitioned into the liquid phase are subsequently transported off the watershed into the local river or stream by the runoff water flow, assuming uniform mixing with the water. The radionuclides that are in the solid phase are assumed to remain on the land surface and be subjected to further dissolution by subsequent rains.

It should be noted that this approach omits two processes that would actually affect the water contamination: (1) the transport of radionuclides down into the soil depths by precipitation that infiltrates the soil, and (2) the transport of radionuclides as particulates, or solid phase material, off the watershed. The omission of radionuclide leaching into the soil will cause the model to overpredict the water contamination; however, this effect is expected to be rather minor and only of concern at late times, e.g., several weeks after the initial fallout contamination. The omission of particulate transport is not likely to be of much significance and is acceptable as long as it is understood that the model is mainly concerned with the radionuclides dissolved in the water.

2.4.5 Aquatic Mixing and Transport

A host of aquatic mixing and transport models are described in the technical literature.[16,22] Most of these models are designed for situations in which the water contaminant is introduced by a continuous, point source. Sophisticated models that can address various mixing and transport parameters and provide time-dependent modeling are also available. In general, however, the available models appeared to be too detailed and too complex to warrant application to this assessment; in addition, it was not obvious that modifications to such models to accomodate a nonpoint contamination source would be warranted.

For the purposes of this assessment, the stream or river within the watershed is assumed to be a "mixing tank" with instantaneous and uniform mixing of the radioactive contaminant with the water. The concentration of the radioactive contaminant at the outlet of the mixing tank (which corresponds to the location of the water supply point) is then determined by the intitial concentration in the tank and the number of volume changes per unit time (the flow rate divided by the tank volume). The initial concentration of the radioactive contaminant is obtained from fallout calculations that give the areal density of deposited radionuclides. Information on the water volume and flow rate for various watershed is obtained from the water supply point study given in Appendix A.

2.5 Water Contamination Model

A simplified computer model has been developed to characterize radiological water contamination.* The Watershed Water Contamination Model (WSWCM) calculates the time-dependent activity concentration of fission product radionuclides dissolved in water that could result from the deposition of nuclear weapons' fallout on a watershed. WSWCM considers both the prompt water contamination that would result from the fallout material deposited directly in the water and the delayed water contamination that would result from the fallout material initially deposited on the land surface and subsequently transported to the water by precipitation runoff. All activity is assumed initially to be associated with solid particulate fallout. The activity may leave the watershed only by radioactive decay or by being dissolved in water which flow past the water supply point.

*A detailed description of the model, WSWCM, is provided in Appendix B.

The principal characteristics of WSWCM are: (1) the watershed is modeled as a mixing tank, (2) radionuclide-specific distribution coefficients are used to address fallout solubility, and (3) the model treats radioactive decay including daughter in-growth. It is important to note that WSWCM addresses radioactive material in solution but does not incorporate any modeling of particulate or sediment transport.

The input data/information used by WSWCM falls into three main areas: (1) fission product radionuclide data, (2) information on watershed and precipitation characteristics, and (3) data and information on the solubility modeling. The data necessary to perform water contamination calculations for the selected scenario area is included in WSWCM. The principal product of WSWCM are plots of the activity concentration in water (pCi/ℓ) as a function of the time since the fallout material was deposited (hr), for specified parent-daughter radionuclide pairs.

WSWCM was applied to a situation in which the initial fallout contamination of a specific watershed was 1 R/Hr at H+1 hour and a rain occurred on the 6th day after the fallout was deposited. The results of the model are shown in the following figures. As can be seen in the figures, three typical types of radionuclide behavior are observed. Figure 3 shows an example of a radionuclide (I-135) that decays so rapidly that it presents an initial, but not a delayed, water contamination effect. Figure 4 shows an example of a radionuclide parent-daughter pair (Sr-90, Y-90) that presents a rather constant level of water contamination. Figure 5 shows an example of a radionuclide parent-daughter pair (Te-131m, I-131) that presents both an initial and a delayed water contamination effect. Finally, Figure 6 shows the composite effect of all the radionuclides considered for the specific problem. Clearly, both the initial and the delayed water contamination processes are of possible significance. In addition, radionuclides having long half-lives and low solubilities could cause a rather persistent water contamination problem.

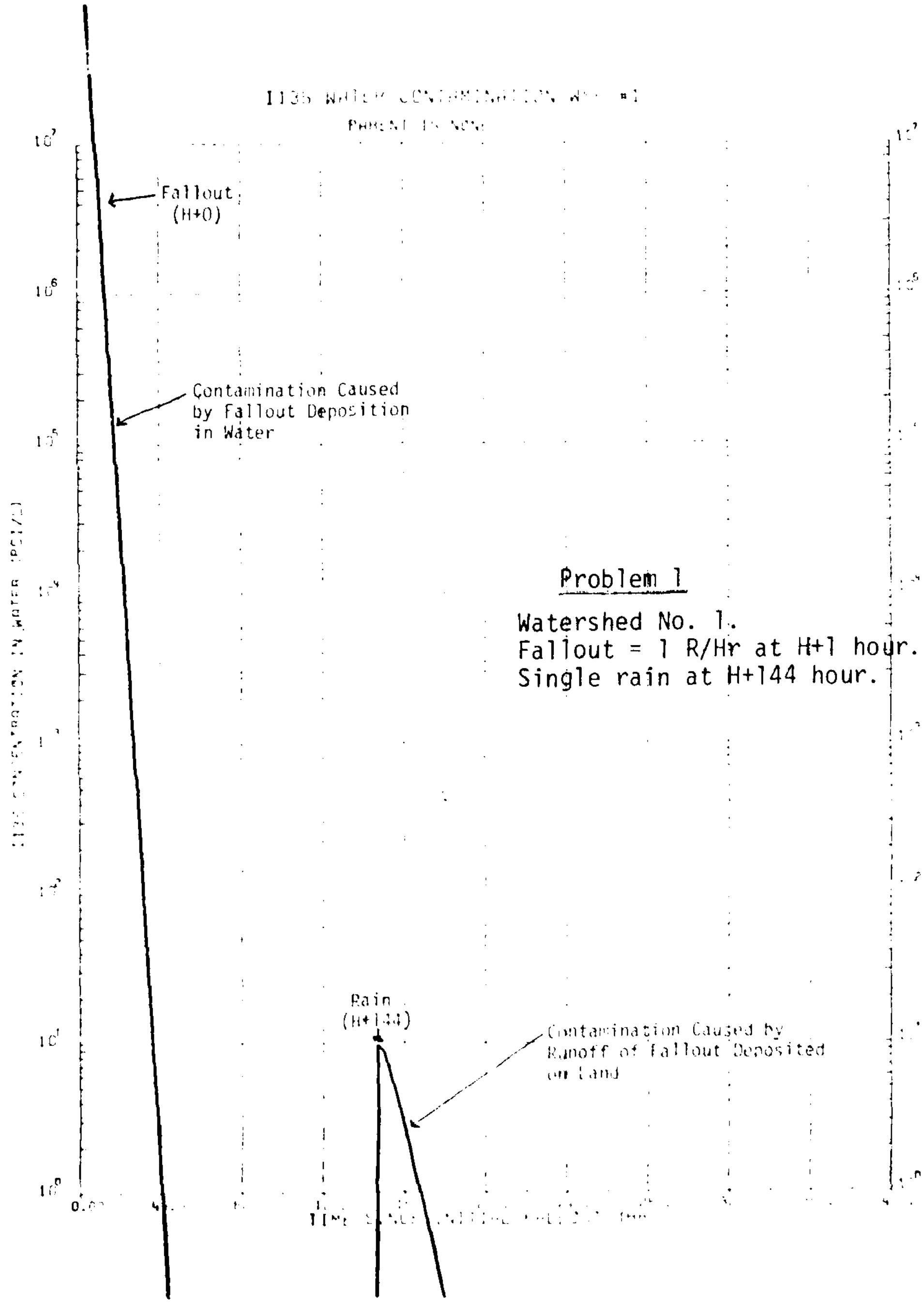


Figure 3. I-135 water contamination - problem 1.

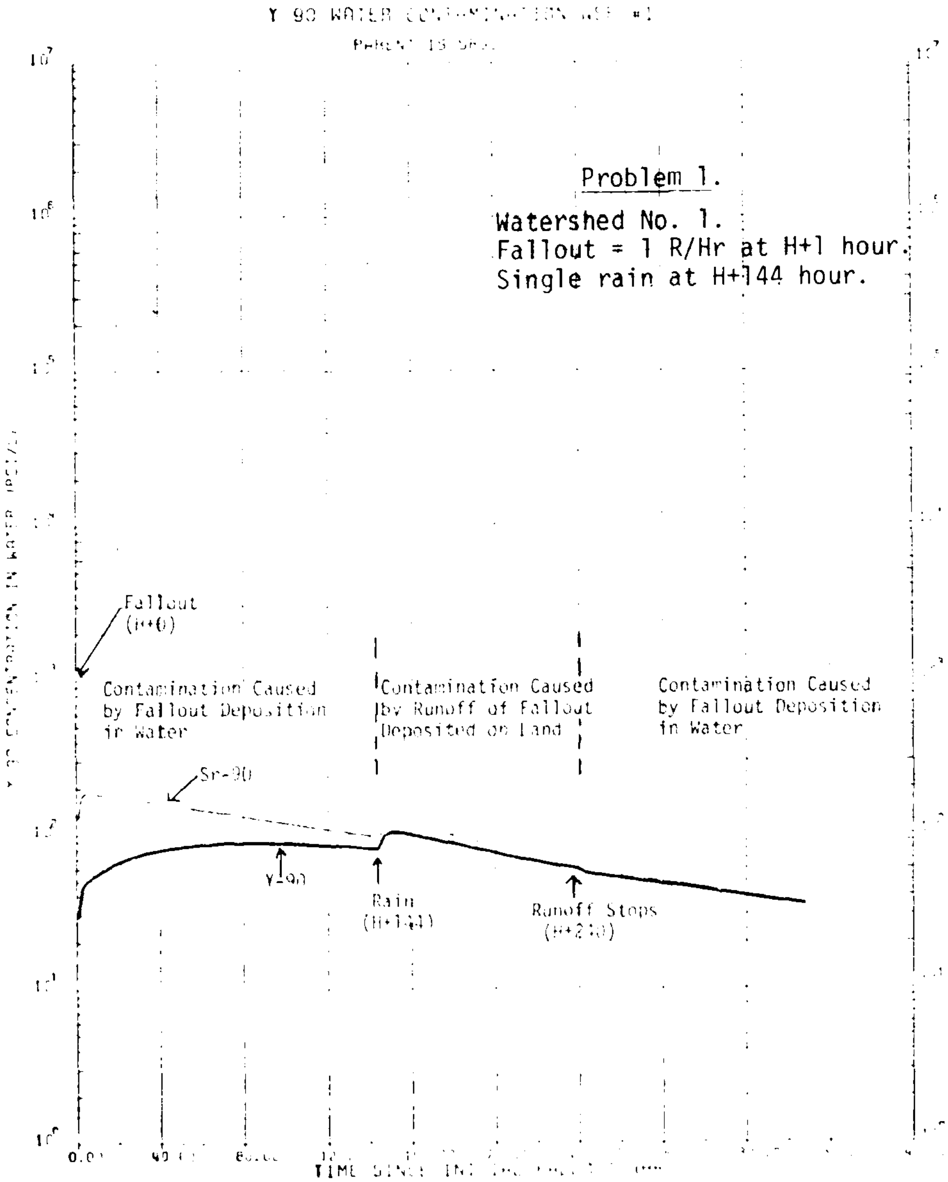


Figure 4. Sr-90, Y-90 water contamination - problem 1.

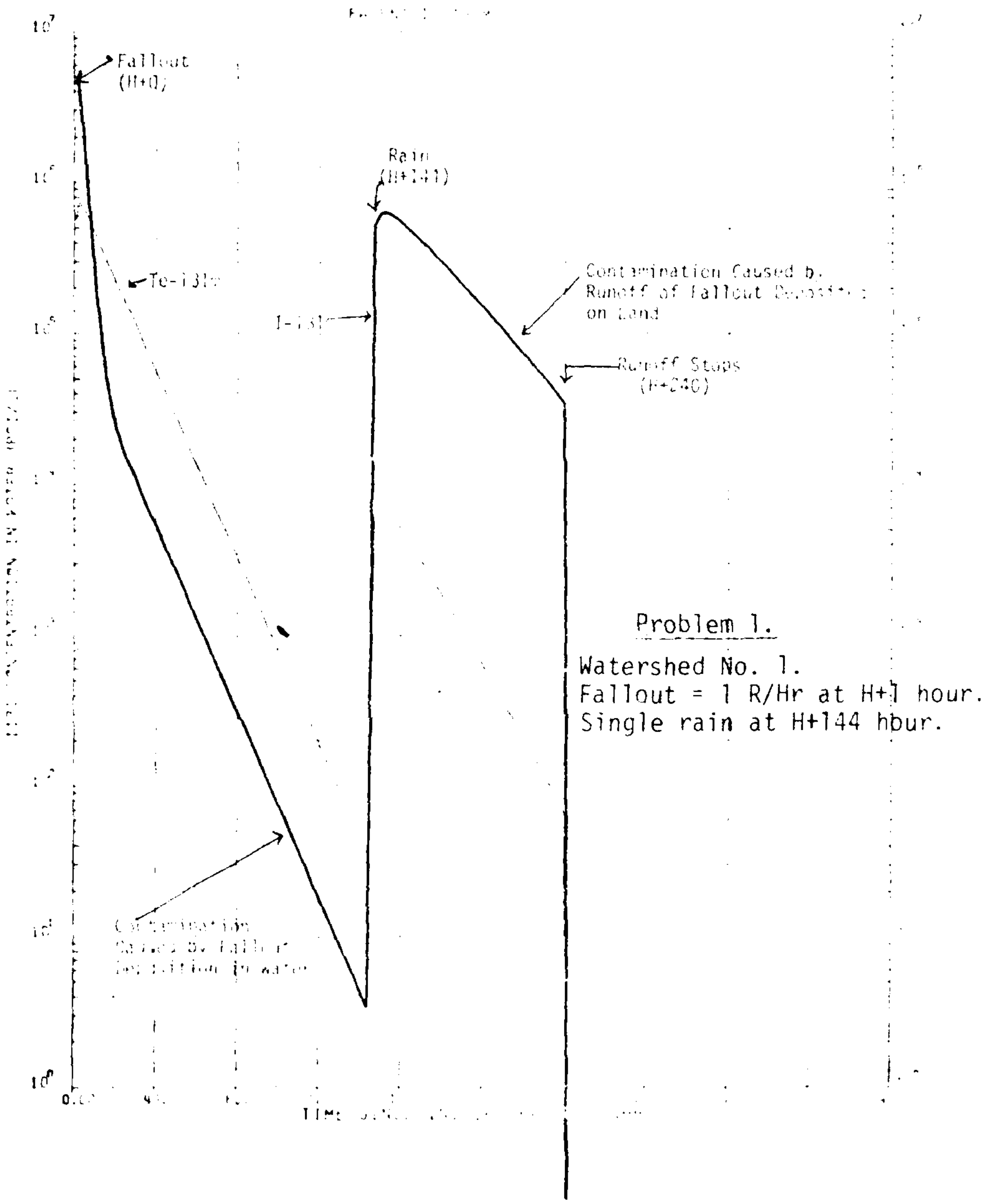


Figure 5. Te-131m, I-131 water contamination - problem 1.

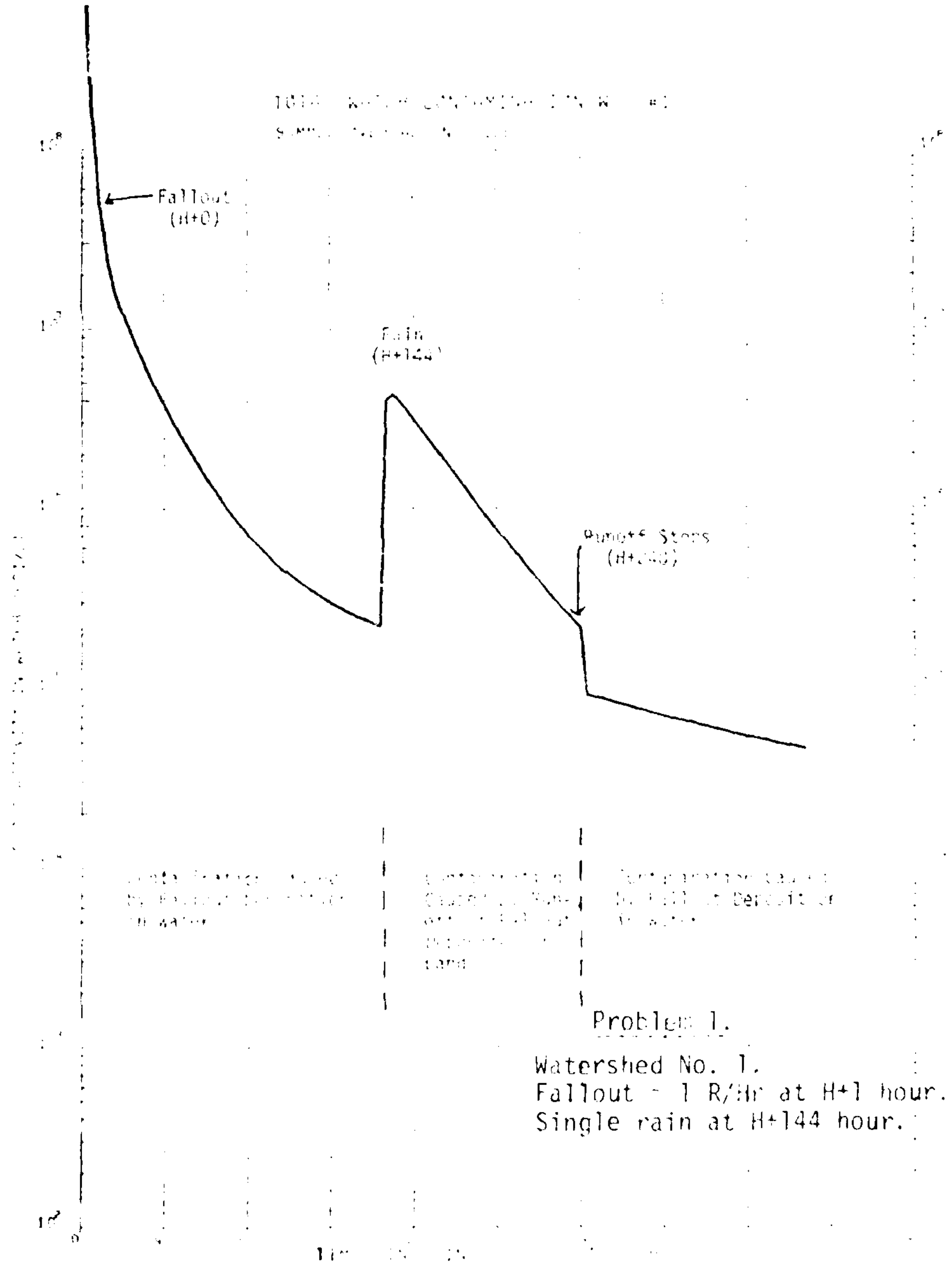


Figure 6. Total (40 radionuclides) water contamination - problem 1.

To better illustrate the above concerns, WSWCS was applied to another watershed that was contaminated at the level of 1 R/Hr at H+1 hour but with 21 rains occurring over a period of about 40 days. The results of this simulation are shown in Figures 7 through 10 for the same radionuclides considered in the previous problem. The presence of persistant water contamination, albeit at a level much below the initial water contamination level, is clearly illustrated.

As seen in the figures, WSWCM provides a convenient tool for analyzing water contamination problems. However, it should be recognized that the model is really quite simple and contains several rather basic assumptions about the behavior of fallout particle radionuclides in water. WSWCM should be considered as a scoping method that provides order-of-magnitude results.

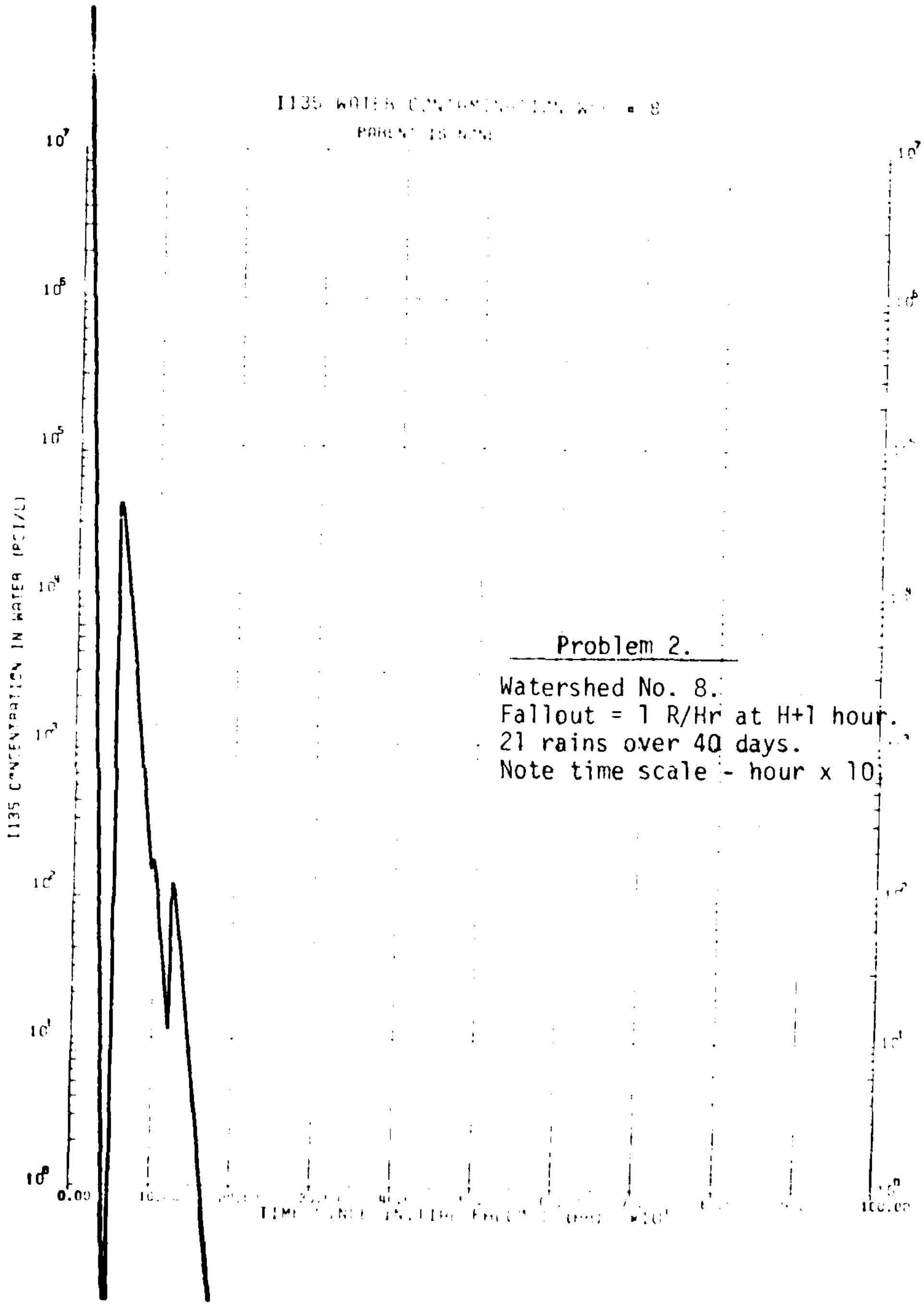


Figure 7. I-135 water contamination - problem 2.

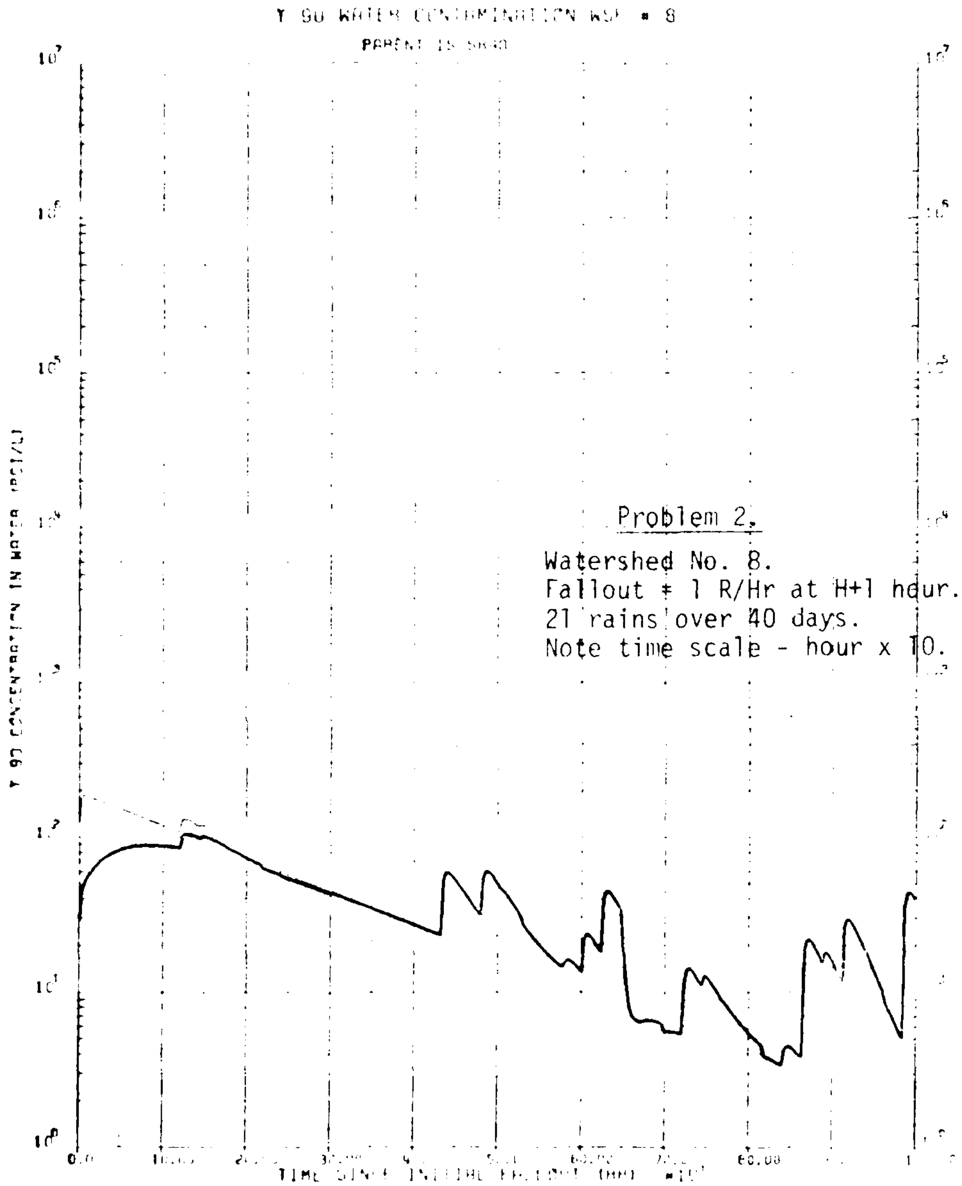


Figure 8. Sr-90, Y-90 water contamination - problem 2.

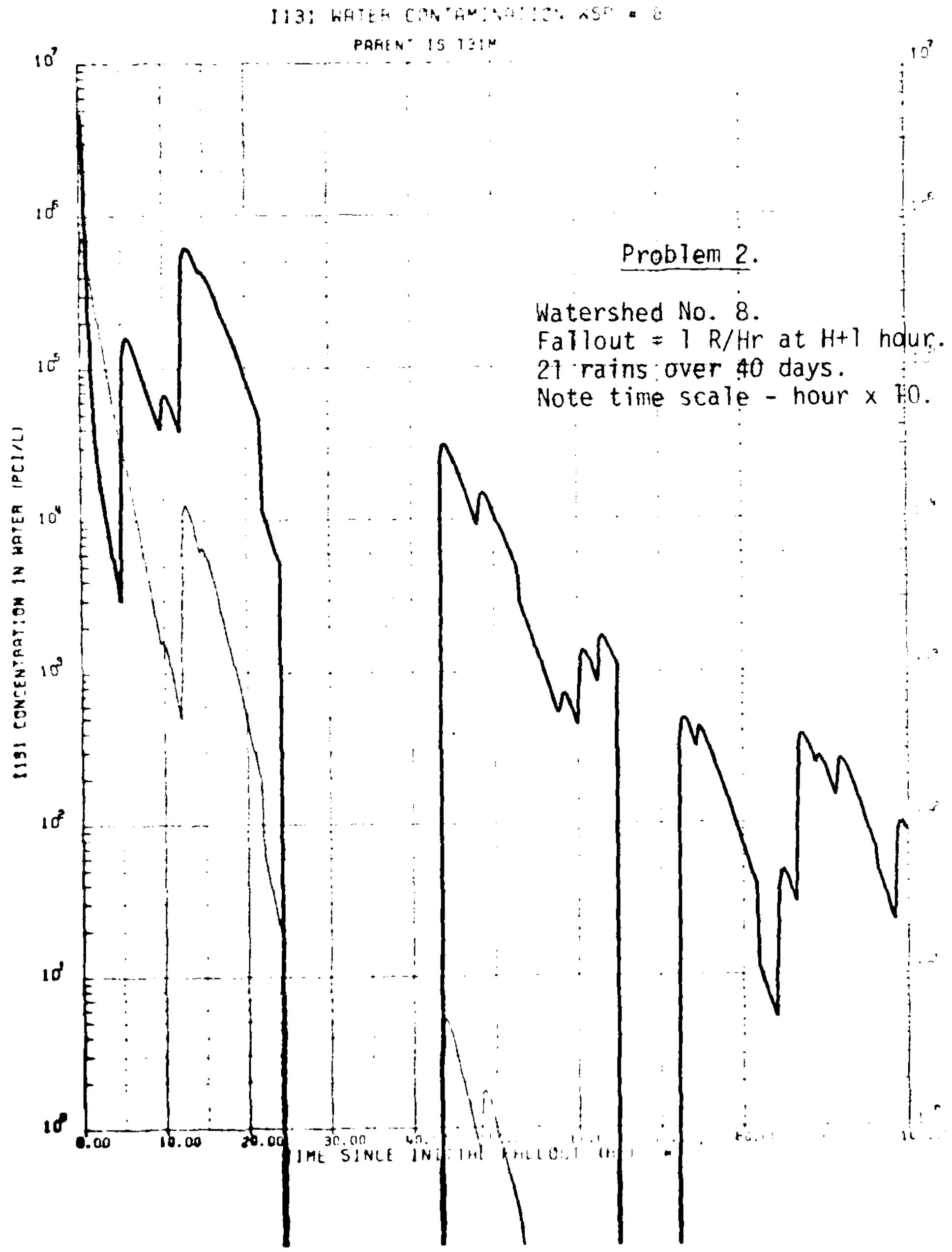


Figure 9. Te-131m, I-131 water contamination - problem 2.

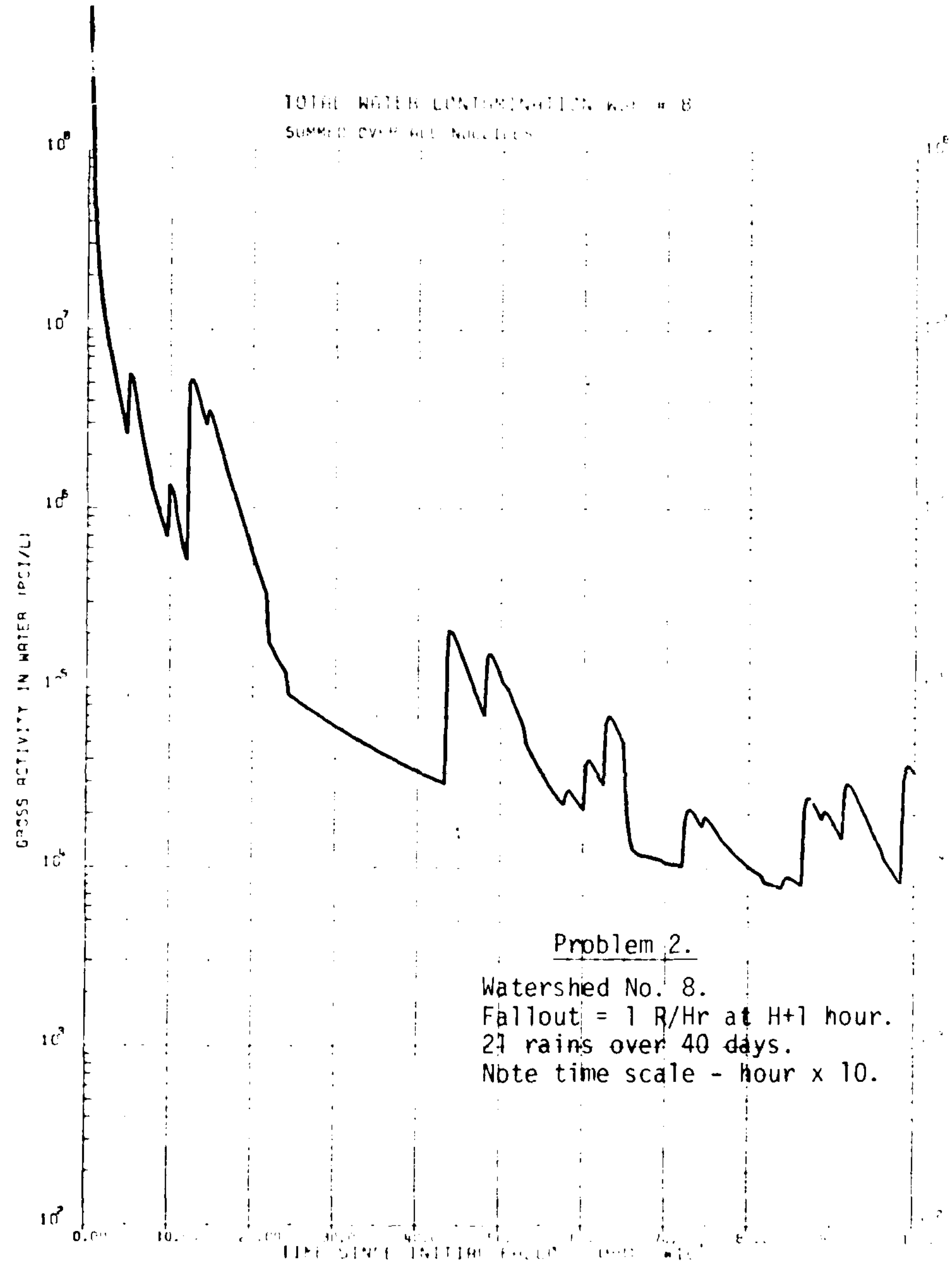


Figure 10. Total (40 radionuclides) water contamination - problem 2.

SECTION 3

THREAT RECOGNITION

3.1 Introduction

Threat recognition refers to the detection and measurement of radiological water contamination. Technical performance criteria for radiation detection and measuring equipment are based on the requirement to show conformance with specified water quality standards. Field-portable radiation detection and monitoring equipment currently available and under development does not appear to have the capability to adequately monitor water contamination at low levels of radioactivity. Procedures for radiation detection and measurement could be used to indicate compliance with water quality requirements, in lieu of demonstrating compliance.

3.2 Water Quality Standards

esently, standards and requirements that relate to radiologically contaminated water are contained in a U. S. Army technical bulletin and a NATO standardization agreement. As discussed below, both of the documents are currently being revised and their final forms cannot yet be ascertained.

The most specific water quality standards regarding water contaminated with radioactive material are given in TB MED 229.[23] TB MED 229 addresses both fixed installation and field water supplies; for field water supplies, radiological water contamination criteria are given for short-term and long-term usage (see Figure 11). The short-term criteria are not specific with regard to acceptable levels of water contamination and no numerical criteria are given. The long-term criteria do provide specific numerical criteria (i.e., 1000 pCi/ gross beta activity and 10 pCi/ strontium-90) by imposing the criteria for fixed installations on the field water supplies.

TB MED 229 Requirements

Radiological Contamination - Field Supplies

Short Term (less than 7 days)	For short term consumption, no absolute numerical standard is recommended or considered necessary. This is based on the conclusion that if the external radiation hazard permits occupancy of the water point, the water is suitable for consumption during occupancy not exceeding the one-week period.
Long Term (more than 7 days)	(Same as for fixed installations) Gross Beta Activity 1000 pC/ Strontium 90 10 pC/

Figure 11. TB MED 229 requirements

TB MED 229 is currently being revised and this revisioning will result in two new technical bulletins. TB MED 576 will address the fixed installation portion of TB MED 229; TB MED 577 will address the field installations portion of TB MED 229. For fixed installations, TB MED 576 will adopt new drinking water standards that impose stringent limits on the allowable radioactivity (i.e., 50 pCi/ℓ gross beta activity and 8 pCi/ℓ strontium-90).

At present, it is not known what requirements will be imposed on field installations by TB MED 577. Since the field installations portion of TB MED 229 will remain in effect until TB MED 577 is published, the new water contamination limits for fixed installations, to be given in TB MED 576, will not be automatically adopted for the field installations. It is possible that TB MED 577 will not specify any numerical criteria for radiological contaminated water.

Radiological water contamination is also addressed in the NATO standardization agreement STANAG 2136 (MED) - Minimum Standards of Water Potability. Figure 12 gives the present standard and proposed NATO and US revisions to the standard. Specific numerical criteria for radiologically contaminated water are not provided by the current standard nor the proposed revisions. It is important to note that the absence of specific numerical criteria does not imply that the consumption of radiologically contaminated water is acceptable. On the contrary, the philosophy behind the non-numerical criteria statements is that any radiation exposure, beyond that attributable to normal background radiation, should be avoided, if at all possible.

At present, the requirements of TB MED 229 are in effect and thus provide technical performance criteria for radiation detection and measuring equipment. Specifically, such equipment must have the capability to demonstrate that water intended for consumption does not contain more than 1000 pCi/ℓ of gross beta activity and more than 10 pCi/ℓ of strontium-90.

STANAG 2136 (MED) - Requirements

*** Present Standard ***

d. Radiological Standards

For short term consumption (1 to 7 days) no absolute maximum tolerance is recommended or considered necessary. This is based on the consideration that if the risk of external radiation is such as to allow the source to be used, then the water will be suitable for drinking during occupancy not exceeding one week

*** NATO Proposed Standard ***

d Radiological Standards

It is undesirable to drink water contaminated with radioactive substances. Consideration should be given as to whether a source of water is likely to be contaminated In some circumstances, sources, such as underground water, may be safely assumed to be uncontaminated Filtered water will be free of insoluble particlates but may still contain soluble radioisotopes such as iodine. If there is any doubt, monitoring of the water should be attempted. This can be achieved simply either by the use of a dose rate monitor placed close to a large sample, e.g., bucketfull or preferably by drying down a sample and using a contamination meter Any water sample showing a reading above background should only be used if no better source is available and the use is essential.

*** US Proposed Standard ***

d Radiological Standards

A standard in the normal sense of definite limits is not appropriate in this case, however, the following procedures should be employed:

1. Areas Having Received Fallout - For short term consumption (1 to 7 days) no absolute maximum tolerance is recommended or considered necessary This is based on the consideration that if the risk of external radiation is such as to allow the source to be used, then the water will be suitable for drinking during occupancy not exceeding one week.
2. Areas Not Having Received Fallout - For short term consumption (1 to 7 days) any water sample showing a reading above background, as measured with a dose rate meter or other suitable method, should only be used if no better source is available and the use is essential This is based on the consideration that personnel should not be subjected to unnecessary radiation exposure.

Figure 12. STANAG 2136 (MED) - requirements

3.3 Radiation Monitoring Equipment

Field-portable radiation detection and measuring equipment for monitoring radiological water contamination has been developed for both military and civilian applications. As discussed below, neither the military equipment nor the civilian equipment appears to be capable of monitoring radiological water contamination at the levels of 1000 pCi/ℓ (gross beta activity) and 10 pCi/ℓ (strontium-90).

The Radiac Set AN/PDR-27 is a low-range, beta-gamma instrument, standard for all Services and used for personnel and equipment monitoring. It has two Geiger-Mueller tubes -- a large tube for low-range detection and a small tube for high-range detection. A beta shield on the large G-M tube permits the measurement of beta activity by using the difference between unshielded ($\beta + \gamma$) and shielded (γ only) measurements. The AN/PDR-27 covers a range of 0 to 500 mR/hr in four decade steps; beta measurements by the difference technique are only possible on the two lowest ranges (0-0.5 mR/hr and 0-5 mR/hr).

The AN/PDR-27 can be used to give a qualitative indication of beta-gamma water contamination by holding the large G-M tube, without the beta shield, about one-half inch from the surface of the water.[24] A reading above background indicates a concentration of an unidentified beta-gamma emitter in excess of 10^6 pCi/ℓ.[25]

Another water monitoring procedure with the AN/PDR-27 has been described by D. C. Lindsten.[26] In this procedure, the large G-M tube, without the beta shield, is encased in a rubber surgical glove and immersed into the water. The minimum level of detection is estimated to be 5×10^5 pCi/ℓ of mixed fission products (beta-gamma emitters) based on correlation data developed using fallout material from nuclear weapons testing.

A new beta-gamma survey meter, Radiac Set AN/VDR-1 is being developed as a replacement for the AN/PDR-27. When used for surface monitoring of contaminated water, the AN/VDR-1 is expected to be able

to detect a beta emitting isotope at the level of 3.5×10^6 pCi/ℓ. At present, the status of the AN/VDR-1 is uncertain, and further development or production might be discontinued.[27]

Radiation detection and measuring equipment developed for civilian applications is described in numerous textbook and other publications.[28-32] In order to supplement such references and determine the current state-of-the-art, a request-for-information was sent to 43 firms identified as providing equipment or services related to the detection and measurement of radiological water contamination. The identification of the firms was based on their cited capabilities listed in the Nuclear News 1981 Buyers Guide.[33] The request-for-information letter expressed an interest in equipment that could measure beta radiation in a mixed beta-gamma contaminated water sample. The range of interest was given as from 3×10^6 pCi/ℓ down to 3 pCi/ℓ, and it was noted that the gamma radiation could be a factor of 10 above, or below, the beta radiation. An interest in both gross beta radiation measurements and specific radionuclide identification was expressed. It was noted that the principal interest was with equipment that could be used for real-time monitoring of a process stream; however, there was also interest in laboratory-type equipment if such equipment could be transportable to the field and provide an analysis within a couple of hours.

Table 6 identifies the firms that were contacted and indicates their responses. Of the 43 firms contacted, 24 did not respond to the request. Of the 19 responding firms, 9 indicated that they did not have the capabilities for measuring the water contamination of interest; 10 firms indicated that they did have some capability and provided relevant literature.

Based on an assessment of the supplier literature and the references cited above, it appears that for process monitoring applications the minimum level of detection is about 10^6 pCi/ℓ gross

Table 6. Responses to request-for-information

Firm	No Response	Negative Response	Positive Response
Anacon, Inc./Aero Vac Products	x		
Applied Health Physics, Inc	x		
Applied Physical Technology, Inc	x		
Aptec Nuclear Inc	x		
The Aston Company	x		
Baird Corp			x
Berthold-Beta Analytical, Inc	x		
Canberra Industries, Inc.			x
Cedar Grove Operations		x	
Centronic Inc			x
Don L. Collins & Assoc.	x		
Dionex Corp.	x		
Dosimeter Corp. of America		x	
Eberline Instrument Co.	x		
EG&G Ortec Inc.			x
Electrometer Corp.	x		
Evans Nuclear Consulting Services	x		
Foxboro Analytical		x	
Gamma-Metrics	x		
General Atomic Co	x		
The Harshaw Chemical Co.			x
High Voltage Engr. Corp.	x		
IRT Corp			x
Kaman Sciences Corp.		x	
National Nuclear Corp.			x
Nuclear Data Inc			x
Nuclear Equipment Chem. Corp	x		
Nuclear Instrument Co.	x		
Nuclear Measurement Corp.	x		
Nuclear Research Corp.	x		
Princeton Gamma-Tech., Inc.			x
Reuter-Stokes, Inc.		x	
J. L. Shepard & Assoc		x	
Technical Assoc.	x		
Technology for Energy Corp.	x		
Teledyne Analytical Inst.		x	
Tennelec, Inc.			x
Tera Corp.	x		
United States Testing Co., Inc.	x		
Victroneen Instrument, Inc.		x	
Westinghouse Electric Corp.	x		
Weston Components		x	
Xetex Inc.	x		
(43)	(24)	(9)	(10)

beta activity and specific radionuclide detection is not possible.* It is possible, however, to measure gross beta activity at a level of 1 pCi/ℓ and determine specific radionuclides, like strontium-90, at levels of 1 to 10 pCi/ℓ by using laboratory-type equipment and procedures. However. the necessary equipment with its radiation shielding and supporting utilities is not field-portable and the procedures, which include chemical processing of the sample and counting times of 24 to 48 hours, are too time consuming and complicated to be used by troops in the field situation.

3.4 Radiation Monitoring Procedures

As discussed above, radiation detection and monitoring equipment does not have the capability to detect radiological water contamination at the levels required to meet current standards (i.e., 1000 pCi/ℓ gross beta activity and 10 pCi/ℓ strontium-90). D. C. Linsten has suggested a procedure, termed "supply-side nuclear water monitoring", that could be used to indicate compliance with the water quality standards.[26]

Lindsten's procedure is based on monitoring the radiologically contaminated water as it passes through the stages of purification rather than monitoring the finished product water. As discussed in Section 4, the water purification stages include: coagulation and filtration, reverse osmosis, and ion exchange. The coagulation and filtration stage is expected to remove all of the insoluble fallout material from the raw water, but not affect the soluble material. The soluble material is expected to be removed with efficiencies of 99% and 99.9% by the reverse osmosis and ion exchange stages, respectively.

*It should be noted that a variety of radiation detection and measuring equipment (and data analysis capability) is available for gamma radiation monitoring. It might be possible to use this technology for water monitoring to achieve lower minimum levels of detection or simplify the water monitoring problem.

Based on the above stated removal efficiencies, water entering the ion exchange stage with a gross beta activity of 10^6 pCi/ℓ will be decontaminated to a level of 1000 pCi/ℓ. Similarly, water entering the reverse osmosis stage with a gross beta activity of 100×10^6 pCi/ℓ will be decontaminated to a level of 10^6 pCi/ℓ. These levels of activity for the water prior to the purification stages are sufficiently high to be measured with existing radiation detection and measuring equipment.

According to Lindsten, water that meets the criteria of 1000 pCi/ℓ gross beta activity will meet the critera of 10 pCi/ℓ strontium-90 for the first 200 days after the nuclear explosion. His argument is based on the fact that for gross fission products the strontium-90 activity is less than 1% of the total fission product activity for decay times less than 0.7 years. Actually, the comparison should be made between the strontium-90 activity and the total activity of those soluble radionuclides present in the process stream between the purification stages. Based on the water contamination model described in Section 2, is appears that the strontium-90 activity is about 1% of the total activity of the radionuclides in solution, thus indicating that the strontium-90 criter would be met if the gross activity criteria were met.*

Lindsten's "supply-side nuclear water monitoring" approach is technically feasible. However, as noted by Lindsten, to implement the procedure the decontamination capabilities of the water purification processes must be precisely known. In particular, it appears that it would be necessary to measure and validate the removal efficiencies of

*It should be pointed out that it is not really correct to compare these activities in such a simple fashion. Actually, one should compare the activities that would be measured by the radiation monitoring equipment.

each process on field equipment while actually deployed. This does not mean that calibration activities would necesarily be required during a wartime situation, but it does mean that the necessary calibration procedures would have to be developed and applied routinely to monitor the status of the water purification equipment to assure its combat readiness.

SECTION 4

THREAT COUNTERMEASURES

4.1 Introduction

Threat countermeasures include water purification equipment and methods, and field operations policy and procedures. The water purification equipment of interest is the Reverse Osmosis Water Purification Unit. The field operations policy and procedures include such measures as water point selection, water treatment scheduling, water storage, etc. As discussed below, this assessment has been primarily concerned with the water purification equipment.

4.2 Water Purification Equipment

To meet the requirements for a multi-purpose water purification unit to provide potable water in the field, the U. S. Army is developing the Reverse Osmosis Water Purification Unit (RWPU). The ROWPU is intended to purify raw water contaminated with biological, chemical, or radiological materials. The ROWPU will be highly mobile and available in 600 GPH (gallons per hour), 1500 GPH, and 3000 GPH units.

The ROWPU produces potable product water from radiologically contaminated raw water by a series of three purification processes: (1) coagulation and filtration, (2) reverse osmosis, and (3) ion exchange. The coagulation and filtration process is intended to remove all of the insoluble radioactive material from the raw water; soluble radioactive material will pass through the coagulation and filtration process unaffected. The reverse osmosis process is expected to remove 99% of the soluble radioactive material; this process will also back-up the coagulation and filtration process by removing any soluble radioactive material that is present. The ion exchange process is expected to remove 99.9% of the soluble

radioactive material. Overall, the ROWPU is expected to remove any insoluble radioactive material present in the raw water and to reduce the concentration of soluble radioactive material in the raw water by a factor of 10^5.

Based on a decontamination factor of 10^5 and a product water criteria of 1000 pCi/ℓ gross beta activity, the ROWPU can effectively handle raw water radiologically contaminated up to the level of 10^8 pCi/ℓ with soluble radioactive material. Based on the water contamination model discussed in Section 2, a watershed contaminated by fallout at a level of 1 R/Hr at H+1 hour would yield water contaminated at a level in excess of 10^8 pCi/ℓ for about 8 to 10 hours. This peak level of contamination would diminish rapidly and, in the absence of water contamination introduced by precipitation runoff, would be less than 10^6 pCi/ℓ within 3 to 4 days. Precipitation runoff could also case the level of water contamination to increase to 10^6 to 10^7 pCi/ℓ within this 3 to 4 day period; precipitation runoff could also cause the level of water contamination to remain at 10^4 to 10^5 pCi/ℓ for several weeks after the fallout had been deposited.

Assuming that the problem of the initial (peak) radiological water contamination can be avoided by water storage or rationing, the ROWPU could initially handle water from an area contaminated by fallout at a level of 1 to 10 R/Hr at H+1 hour. After about 4 days, the ROWPU could handle water from areas contaminated by fallout at a level of about 100 R/Hr at H+1 hour. For several weeks after the fallout deposition, the ROWPU would still be needed to purify the raw water to acceptable potable water criteria.

As was shown in Section 2, surface burst nuclear weapons can produce fallout contamination of rather large areas. However, to estimate the extent and the intensity of such fallout contamination in the event of nuclear warfare requires major assumptions regarding the nature of the nuclear strikes, the yields of the weapons, and the prevailing meteorological conditions. Statements about the adequacy of ROWPU to provide potable water in the nuclear warfare environment can

only be made in the context of a specific nuclear warfare scenario. Since this assessment does not address such scenarios, no specific comments on the adequacy of ROWPU are offered.*

However, this assessment has identified two design-related areas that merit special mention. First, the ROWPU should include within its design those features and support equipment that provide a capability for in-field testing of the removal efficiencies of the purification processes; this capability will be of paramount importance if concepts such as "supply-side nuclear water monitoring" are adopted. Second, the ROWPU should have an availability characteristic, achieved through low equipment failure rates and short maintenance/repair times, adequate to ensure that the equipment can be operated nearly continuously for several weeks.

4.3 Field Operations Policy and Procedures

Field operations policy and procedures could complement the water purification equipment to provide countermeasures to the potential radiological water contamination threat. The policy and procedures inc'ude water point selection, water treatment scheduling, water storage, etc.

The effectiveness of such countermeasures can only be examined in the context of specific nuclear warfare scenarios and force

---

*Earlier in this assessment, a nuclear warfare scenario including force deployments was developed. For this scenario, radiological ware contamination was not a significant problem because: only a few surface bursts occurred, the prevailing wind was blowing away from the area where the U. S. forces were deployed, and the wind shear was so small that the fallout pattern exhibited little width. However, during the development and analysis of the scenario it became clear that a single, unique, hypothetical scenario does not provide an adequate basis for making judgments on the worth or utility of water purification systems or related policy and procedures.

deployments. Since this assessment does not address such scenarios, no specific comments on the utility of field operations policy and procedures are offered.

However, this assessment has identified two aspects of field operations that merit special mention. First, sufficient product water storage capability should be available to satisfy requirements if the water purification units have to curtail operations for about a day because of an inability to handle the intial (peak) radiological water contamination. Second, strict radiological defense measures should be maintained in effect until proper radiological water contamination monitoring has determined that the problem no longer exists; such procedures are important because the water could remain radiologically contaminated even after area radiation monitoring does not detect any military significant fallout.

SECTION 5

CONCLUSIONS

In the event of nuclear warfare with nuclear weapons employed in a surface burst mode, the fallout contamination of watersheds and water supplies would be sufficiently high to require the use of water purification equipment to produce potable water that meets the current water quality standards. This problem of radiologically contaminated water could persist for many weeks.

The existing radiation detection and measuring equipment is not capable of verifying that suspect water actually meets the current water quality standards; in fact, the minimum detectable level of radioactivity in water with the existing equipment and procedures is about a factor of 1000 above the current radiological water quality standard. An indication of acceptable water quality can be obtained by a procedure that involves measuring the activity of the water prior to processing, provided the decontamination efficiency of the water purification system is known.

The water purification equipment currently under development can decontaminate, to the current radiological water quality standards, water from a watershed contaminated by fallout at a level of 1 to 10 R/Hr at H+1 hour. After about 4 days, the equipment could effectively decontaminate water from a watershed contaminated at a level of about 100 R/Hr at H+1 hour. The water purification equipment could be needed for several weeks after the fallout deposition.

SECTION 6

REFERENCES

1. Glasstone, S. and P. J. Dolan, "The Effects of Nuclear Weapons", U. S. Department of Defense and Energy, Washington, D. C., 1976.

2. Private Communication, R. Gminder (SAI-McLean) to J. C. Phillips (SAI-Chicago), October 15, 1981.

3. "A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants," NUREG/CR-2300 (Review Draft) U. S. Regulatory Commission, Washington, D. C., September 1981.

4. "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle," ERDA-76-43, U. S. Energy Research & Development Agency, Washington, D. C., May 1976.

5. "Storage of U. S. Spent Power Reactor Fuel," DOE/EIS-0015-D, U. S. Department of Energy, Washington, D. C., August 1978.

6. "DELFIC: Department of Defense Fallout Prediction System", DNA-5159F-1 (Fundamentals) and DNA-5159F-2 (Users Manual), Defense Nuclear Agency, Washington, D. C., December 1979.

7. Egbert, S. D., et al., "FIIDOS-Fallout Inventory and Inhalation Dose to Organs," Unpublished Report, Science Applications, Inc., Schaumburg, Illinois, July 1981.

8. Killough, G.G., et al., "Estimates of Internal Dose Equivalent 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilties," ORNL/NUREG/TM-190, Oak Ridge National Laboratory, Oak Ridge, Tennesse, June 1978.

9. Kocher, D. C., "Dose-Rate Conversion Factors for External Exposure to Photon and Electron Radiation from Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities", in Health Physics, 38, pp. 543-621, 1980.

10. Larson, K. H., et al., "Distribution, Characteristics, and Biotic Availability of Fallout, Operation PLUMBBOB," WT-1488, Civil Effects Test Group, July 1966.

11. Miller, C. F., "Fallout and Radiological Countermeasures", AD410522, Standford Research Institute, Menlo Park, California, January 1963.

12. Brown, S. L. et al., "Agricultural Vulnerabilty to Nuclear War," Stanford Research Institute, Menlo Park, California, February 1973.

13. Brown, S. L., et al., "Postattack Food Production and Food and Water Contamination," Stanford Research Institute, Menlo Park, California, June 1968.

14. Sullivan, R. J., et al., "Survival During the First Year After a Nuclear Attack," SPC 488, System Planning Corporation, Arlington, Virginia, September 1979.

15. Norman, J. H. and P. Winchell, "Physical, Chemical, and Radiological Properties of Fallout," in "Survival of Food Crops and Livestock in the Event of Nuclear War," ACE Symposium Series 24, U. S. Atomic Energy Commission, Washington, D. C., December 1971.

16. Onishi, Y., et al., "Critical Review: Radionuclide Transport, Sediment Transport, and Water Quality Mathematical Modeling; and Radionuclide Adsorption/Desorption Mechanisms," NUREG-CR-1322 (PNL-2901), Pacific Northwest Laboratory, Richland, Washington, January 1981.

17. Helton, J.C. and P. C.Kaestner, "Risk Methodology for Geologic Disposal of Radioactive Waste: Model Description and User Manual for Pathways Model," NUREG/CR-1636 (SAND 78-1711), Sandia National Laboratories, Albuquerque, New Mexico, March 1981.

18. Schreckhise, R. G., "Simulation of the Long-Term Accumulation of Radiocontaminants in Crop Plants," PNL-2636, Pacific Northwest Laboratory, Richland, Washington, March 1980.

19. Novotny, V. and G. Chester, "Handbook of Nonpoint Pollution: Sources and Management," Van Nostrand Reinhold Company, New York 1981.

20. "The Effects on Population of Exposure to Low Levels of Ionizing Radiation," Natinal Academy of Sciences, Washington, D. C., 1972.

21. "Long-Term Worldwide Effects of Multiple Nuclear Weapons Detonation," National Academy of Sciences, Washington, D. C., 1975.

22. "Estimating Aquatic Dispersion of Effluents from Accident and Routine Reactor Releases for the Purpose of Implementing Appendix I," Regulatory Guide 1.113, U. S. Nuclear Regulatory Commission, Washington, D. C., April 1977.

23. "Sanitary Control and Surveillance of Supplies at Fixed and Field Installations," TB MED 229, Department of the Army, Washington, D. C., August 1975.

24. "Operational Aspects of Radiological Defense," FM 3-12, Department of the Army, Washington, D. C., August 1968.

25. "Nuclear Accident Contamination Control," FM 3-15, Department of the Army, Washington, D. C., June 1966.

26. Private Communication, D. C. Lindsten (USAMERADCOM) to John C. Phillips (SAI-Chicago), March 31, 1982.

27. Private Communication,R. Gminder (SAI-McLean) to J. C. Phillips (SAI-Chicago), October 1981.

28. Knoll, G. F., "Radiation Detection and Measurement," John Wiley & Sons, New York, 1979.

29. Eichholz, G. G., "Environmental Aspects of Nuclear Power," Ann Arbor Science, Ann Arbor, Michigan, 1979.

30. "Environmental Radiation Measurements," NCRP Report No. 50, National Council of Radiation Protection and Measurements, Washington, D. C., December 1976.

31. "Instrumentation and Monitoring Methods for Radiation Protection," NCRP Report No. 57, National Council on Radiation Protection and Measurements, Washington, D. C., May 1978.,

32. "A Handbook of Radioactivity Measurements Procedures," NCRP Report No. 58, National Council on Radiation Protection and Measurements, Washington, D. C., November 1978.

33. "Nuclear News 1981 Buyers Guide, "American Nuclear Society, LaGrange Park, Illinois, March 1981.

APPENDIX A

WATER SOURCE INFORMATION

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION A-1

INTRODUCTION

This appendix provides descriptive information on water sources within the Western European area of concern. This area is bounded by Marburg (Lahn), Giessen, and Frankfurt am Main on the west and the Fulda River valley on the east. The information is used to identify typical water point sites; characterize the watersheds, region, and climate; and provide an approach to watershed modeling.

The assistance of the following individuals in obtaining appropriate references, determining applicable factors, and identifying potential resources is gratefully acknowledged:

Mr. William Abbe, Terrain Analysis Center,
Engineer Topographic Laboratories, Ft. Belvoir, VA

Captain Molzahn, Department of Military Engineering,
U. S. Army Engineer School, Ft. Belvoir, VA

Mr. Henry Zoller, Library, U. S. Geology Survey,
Reston, VA

Ms. Laurie Stackpole and Mrs. Rouse, Library, National
Oceanic and Atmospheric Administration, Rockville, MD

Mr. Richard Farnsworth and Dr. Michael Hudlow,
Hydrology Laboratory, National Oceanic and Atmospheric
Administration, Silver Springs, MD

Mr. Bruce White and Mr. Charles White, New England River
Forecast Center, U. S. Weather Service, Bloomfield, CT

SECTION A-2

WATER SUPPLY POINTS

Water supply points are selected to support troops units on an area basis. Thus, a water point would serve all water supply trucks and trailers coming to it and not just support a specific unit. The typical field water purification equipment is oriented for use of surface water supplies. The Army organization includes well drilling capability but this would not normally be used in an area such as Germany. The Division is equipped with five 1500 gallon per hour water point units. Additional 1500 gph units are operated by Corps Combat Battalions, and 3000 gph units are operated by the Corps Water Supply Company.

Water supply points are sited on the bases of:

- Adequate Source, minimum of 2000-3000 gph (to allow for waste due to backflushing) (equivalent to approximately 2-1/2 liters per second) per 1500 gph unit. These values would be doubled for the 3000 gph treatment unit.
- Adequate Road Net, to permit all weather vehicle access to the fill station in the immediate vicinity of the treatment unit, and to allow for turn arounds and waiting vehicles.
- Cover and Concealment, forested locations are desirable, placement of points in towns or in the vicinity of logical targets would be avoided (e.g., major intersections, bridge sites, troop concentrations).
- Good Drainage and above typical flood levels.
- Avoidance of Upstream Sources of Contamination, such as industries, major towns, sewer outfalls, or stagnant water (marshes, swamps, flooded fields).

The above doctrine was used to identify typical water supply points in the area of concern. Three points were identified on each of 10 map sheets (4 points on one of these sheets), to permit

characterization of typical points. Other points could have been readily identified, due to the amount of runoff, number of streams and excellent road nets in the area. Watersheds which would provide at least 5 liters per second at the water point were chosen (approximate minimum for 3000 gph unit). The low flow values of 1 to 2 liter per second per square kilometer to be expected in the region indicated that drainage areas of at least 5 square kilometers should be chosen. The criteria of avoiding upstream sources of contamination, where feasible, and the distribution of towns and villages indicated that small drainage areas be chosen when available. The above criteria and considerations of vehicle access and proximity to an extensive road network were used in identifying the water supply points (WSP) listed in Table A-1. The watershed areas were delineated on copies of the identified map sheets.

Table A-1. Stream flow parameters for water supply point locations.

Map Sheet 1:50000	WSP Grid Coordinates (UTM)		Area Km^2	Main Stream Length Km	Distance to Center of Area (Km)	Difference in Elevation (m)	C_T (Snyder's Synthetic Procedure)	Time to Peak Flow* (Hours)
L5318	(4)822	(56)180	63 6	15 7	5.8	203	2.2	6.4
L5318	879	095	10.0	5 6	1 4	105	2.2	3 1
L5318	916	229	12 6	7 5	3 2	165	2.1	4.1
L5320	(5)049	(56)228	27 1	7.3	2.7	109	2.2	4 0
L5320	133	183	12.8	9.0	4 0	112	2.2	4 8
L5320	156	176	28.1	9.1	3 5	186	2.2	4.7
L5320	195	118	12.2	8.0	3 6	188	2.1	4.3
L5322	317	170	30.9	5.0	2.0	186	2.0	3.0
L5322	402	180	13.6	5.6	2.5	254	1.9	3.2
L5322	403	200	7.9	5.8	3.0	192	2 0	3.5
L5520	035	009	12.4	9.7	4 5	340	2.0	4.7
L5520	(5)098	(55)858	16.6	11 4	5 3	386	2.0	5.1
L5520	(5)208	(56)027	9.3	6 7	3.2	273	2.0	3.8
L5522	(5)371	(55)988	21.4	7.9	3.9	220	2.1	4.4
L5522	402	891	33.0	14.4	7.2	294	2.2	6.7
L5522	422	901	17.4	9.1	3.2	222	2.1	4.3
L5720	078	725	10.8	6.9	2 3	248	2.0	3.4
L5720	087	694	8.4	6.3	2.6	224	2.0	3.5
L5720	144	671	20 5	8.1	3.9	226	2.1	4.4
L5722	275	690	22.1	6.9	3.3	346	1.9	3.6
L5722	387	682	8.7	7 7	3.1	255	2.0	3.9
L5722	427	687	14.3	8 1	3.1	233	2.1	4.2
L5724	525	612	19.9	8 6	4 0	260	2.1	4.6
L5724	539	789	31 7	12.8	4.6	500	2.0	5.1
L5724	689	619	45.3	16.3	6.4	556	2.0	6.1
L59[illegible]	120	454	15.4	5.9	[illegible]	232	2.0	3.4
L5920	192	466	9.5	4.7	[illegible]	290	1.8	2.6
L5920	194	588	12.5	5.4	[illegible]	[illegible]	[illegible]	3.0
L5922	296	460	25.8	9.9	4.2	230	2.1	4.8
L5922	417	557	24.7	7.4	4.0	[illegible]	1.9	3.9
L5922	451	455	40.2	11.8	4.2	374	2.0	4.8

*Also - Time after start of rain when all of watershed is contributing rain runoff to flow at WSP (Water Supply Point).

SECTION A-3

GENERAL HYDROLOGIC INFORMATION

The region consists of rolling terrain, forested or under agriculture. There are generally sources of large quantities of surface water in the lower part of the area of concern less than 8 kilometers apart; and in the upper part of the area, moderate quantities of surface water from sources less than 16 kilometers apart. There are generally uniform amounts of rainfall throughout the year with somewhat more rainfall (by 30 to 50%) occurring in the months of June, July, and August and the least amounts in February, March, and April. Due to the differences in evaporation losses, however, the largest runoff occurs during the months of November through April (which constitute the "Winter Semester" for German hydrologic studies). This as shown in Figure A-1 and Table A-2 for the area of concern. Summary average precipitation data for selected stations are shown in Table A-3.

Typical runoff from watershed averages from 5 to 15 liters per second per square kilometer, with the lower values usually associated with smaller watersheds. Table A-4 illustrates mean and absolute high and low runoff rates and average rates for several watersheds of the Fulda River basin, which overlaps the area of concern. Typically, the flow is less than the mean flow 240 to 280 days per year, due to the amount of runoff directly associated with storms. The flow does not exceed 50 to 60 percent of the mean flow half of the days. Flow less than 2 liters per second per square kilometer of watershed occur very rarely, and for streams which have recorded such low flows the frequency is generally less than 2% of the time.[(A-1)*]

*The number in the parentheses denotes a reference that is identified in Section A-6.

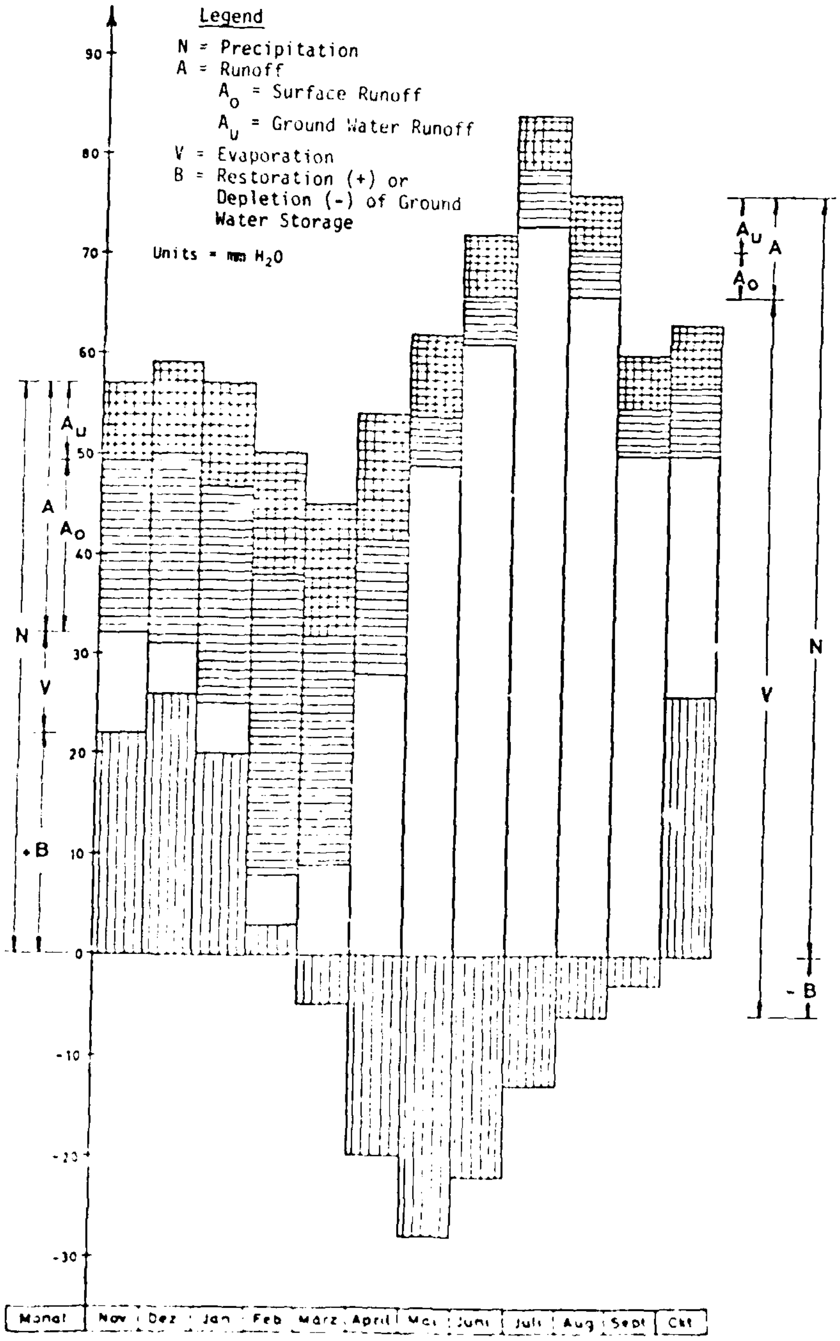


Figure A-1. General precipitation runoff audit.

Table A-2. Precipitation-runoff audit, Fulda region.

Entries in mm of Water on the Drainage Area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N	57	50	45	55	62	72	84	76	60	63	57	59
Av	10	12	13	13	8	6	5	5	5	6	8	9
Ao	22	30	23	14	5	5	6	5	5	7	17	19
V	5	5	9	28	49	61	73	66	50	24	10	5
B	+20	+3	-5	-20	-28	-22	-13	-6	-3	+26	+22	+26
A	32	42	36	27	13	11	11	10	10	13	25	28
A/N	.56	.84	.80	.49	.21	.15	.13	.13	.17	.21	.44	.47
Ao/A	.69	.71	.64	.52	.38	.45	.55	.50	.50	.54	.68	.68
	Average Runoff in Liters Per Second Per Square Kilometer											
Av´	3.7	5.0	4.9	5.0	3.0	2.3	1.9	1.9	1.9	2.2	3.1	3.4
Ao´	8.2	12.4	8.6	5.4	1.9	1.9	2.2	1.9	1.9	2.6	6.6	7.1

Legend

N - Precipitation (mm)

A_v - Ground Water Runoff (mm)

A_o - Surface Runoff (mm)

V - Evaporation (mm)

B - Restoration (+) or Depletion (-) of Ground Water Storage (mm)

A - Total Runoff (mm)

A/N - Total Runoff/Precipitation Ratio

A_o/A - Surface Runoff/Total Runoff Ratio

A_v' - Ground Water Runoff (ℓ/s/km)

A_o' - Surface Runoff (ℓ/s/km^2)

Table A-3. Selected climatological data - West Germany.

Parameter	Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annually
Mean Precipitation (")	Frankfurt Am Main (FaM)		1.7	1.4	1.6	1.5	1.9	2.2	2.5	2.7	2.0	2.2	1.9	2.1	23.7
	Fulda		1.7	1.3	1.5	1.8	2.4	2.5	3.0	2.8	2.2	2.2	1.8	1.9	25.1
	Giessen		1.8	1.4	1.4	1.6	2.0	2.4	2.9	2.4	1.9	2.2	1.8	2.0	23.8
	Marburg		2.0	1.6	1.7	1.7	2.0	2.3	2.7	2.5	1.9	2.4	2.0	2.3	25.1
	Wesserkampf		3.6	3.2	3.0	3.3	3.0	3.7	4.8	4.2	3.8	3.6	2.8	3.3	42.3
Greatest & Least Precipitation (")	FaM	Max	3.7	3.4	4.0	4.0	4.5	5.3	4.9	8.4	4.3	6.7	4.6	4.6	35.0
		Min	0.5	<0.05	0.1	0.0	0.2	0.5	<0.05	0.6	0.1	0.2	0.6	0.6	14.1
	Fulda	Max	3.9	2.6	3.7	4.0	6.3	6.1	5.6	5.6	4.1	5.9	4.1	3.9	30.4
		Min	0.6	<0.05	0.2	<0.05	0.5	0.3	0.6	0.3	0.4	0.2	0.3	0.2	17.3
	Giessen	Max	3.9	3.0	3.0	5.0	4.5	4.6	8.5	5.5	3.9	7.4	3.9	4.6	32.3
		Min	0.5	0.1	0.1	0.0	0.3	0.3	0.6	0.4	0.3	0.2	0.4	0.4	16.5
	Marburg	Max	4.6	3.1	3.6	4.1	5.1	5.2	4.8	5.8	3.9	7.4	4.7	5.7	32.6
		Min	0.6	0.1	0.1	0.0	0.4	0.2	0.3	0.1	0.3	0.2	0.4	0.5	14.3
Mean No. of Days with Precipitation ≥ 0.004"(0.1mm)	FaM		15	13	13	14	13	13	14	14	12	14	14	17	166
	Fulda		16	13	14	14	14	15	15	16	14	15	15	18	179
	Giessen		17	14	15	14	14	13	15	14	14	15	15	17	177
	Marburg		18	14	15	14	14	13	15	14	13	16	16	18	180
Mean No. of Days with Precipitation ≥ 0.4"(10mm)	FaM		1	1	1	1	1	2	2	2	1	1	1	1	15
	Fulda		1	1	1	1	2	2	2	2	1	1	1	1	16
	Marburg		1	1	1	1	1	1	2	2	1	1	1	1	14
Max 24-hr Precipitation	FaM		1.3	0.7	0.6	1.1	2.2	2.6	1.5	1.7	1.4	1.4	1.5	1.2	2.6
	Fulda		1.2	0.7	1.3	0.9	2.6	2.4	1.9	2.1	2.2	1.5	1.0	1.0	2.6

Intense Short Period Precipitation: Marburg 0.02"/minute for 26 minutes 0.51" accumulation in a May

Mean Dates of First Formation and Final Melting of Snow Cover		
	FaM	4 December - 9 March
	Fulda	13 December - 17 March
	Marburg	21 November - 19 March

Table A-4. Summary runoff data for selected stations.

Station	Drainage Area (km²)	Flow Rate (m³/s) Mean Flow	Mean Low Flow	Mean High Flow	Recorded Low Flow	Recorded High Flow	Flow Rate Normalized to Drainage Area (l/s-km²) Mean Flow	Mean Low Flow	Mean High Flow	Recorded Low Flow	Recorded High Flow
Affoldern	1452.	19.9	1.63	236.	0.20	585.	13.7	1.12	162.	0.14	403.
Asel	18.0	0.10	0.03	1.5	0.02	3.5	5.40	1.54	82.5	1.05	193.
Bonaforth	6933	56.2	9.40	519.	2.70	1340.	8.10	1.36	74.8	0.39	193.
Dalwigksthal	230.	3.36	0.23	38.6	0.01	75.0	14.6	1.00	168.	0.43	326.
Dammeshof	79.0	0.41	0.20	1.4	0.08	10.0	5.17	2.53	17.7	1.00	127.
Eudorf	132.	0.93	-	-	0.32	20.0	7.02	-	-	-	151.
Fulda (Horas)	538.	6.29	1.14	60.9	0.23	164.	11.6	2.11	113.	0.43	303.
Grebenau	2975.	22.4	5.80	141.	2.50	520.	7.52	1.95	47.5	0.84	175.
Guntershausen	6366.	52.6	8.30	519.	2.10	1320.	8.26	1.30	81.6	0.33	207.
Heiligers	20.9	0.21	0.10	1.3	0.02	10.0	10.1	4.77	62.3	0.95	480.
Hersfeld	2127.	17.4	5.00	150.	1.20	400.	8.21	2.36	70.8	0.57	189.
Herzhausen	68.1	0.58	0.29	6.3	0.22	12.6	8.51	4.25	92.3	4.23	185.
Hutzdorf	312.	2.71	1.59	9.0	0.20	110.	8.70	4.81	28.9	0.64	353.
Kämmerzell	563.	6.43	1.55	82.6	-	66.8	11.5	2.76	147.	-	-
Malsfeld	2740	20.5	4.30	223.	1.50	656.	7.48	1.57	81.3	0.55	240.
Mosse	124	3.33	0.24	37.2	0.05	75.0	26.7	1.93	299.	0.40	602.
Niederwerbe (Reinerbach)	27.2	0.12	0.03	1.8	0.01	4.3	4.41	1.18	67.2	0.37	156.
Niederwerbe (Werbebach)	41.9	0.23	0.09	3.5	0.04	10.0	5.39	2.05	82.8	0.84	239.
Pauland	84.6	2.26	0.16	24.8	0.03	69.0	26.7	1.89	293.	0.36	816.
Rotenburg	2523.	19.2	3.90	228.	1.40	492.	7.65	1.55	90.6	0.56	195.
Schmittlotheim	1202.	18.7	1.47	220.	0.10	770.	15.6	1.22	183.	0.08	640.
Schreufa	139.	2.70	0.15	42.5	0.06	61.5	19.4	1.08	306.	0.43	443.
St...hausen	91.6	0.74	0.40	5.4	0.05	170.	8.07	4.37	59.0	0.55	186.
Treysa	548.	3.02	0.68	30.9	0.32	51.0	5.52	1.24	56.5	0.58	93.
Unterschwarz	1211.	11.7	7.00	260.	1.00	400.	9.72	5.82	-	0.83	333.
Wehrda	370.	2.31	0.49	28.2	0.20	65.0	7.52	1.31	75.3	0.53	174.
Wolfershausen	3322.	23.9	1.70	281.	1.30	403.	8.70	0.51	84.5	0.39	121.

*Data are for selected central German stations. Period of record is 1936-1955. Reference: "Wasserwirtshaftlicler Rahmenplan Fulda," 1964.

As illustrated above, the most runoff is surface runoff; the total runoff is a small fraction of precipitation most of the year; and precipitation occurs frequently (on almost half the days) throughout the year, but on only an average of one or two days a month is the precipitation sufficient to cause significant runoff occur.

The threshold amount of precipitation for causing runoff varies during the year, due to changes in temperature, growing vegetation, and sunlight, and due to the relative permeability of the surface due to prior precipitation, snow cover, or frozen ground.

The amount of area covered by water surface is a small fraction (1-3%) for the region, with even lower values typical of watersheds for illustrative water supply points.

The rivers in the area are characterized by having high levels of chemical and biological contamination. Lakes, ponds, and small streams contain less contamination, however, use of water purification equipment is considered essential. Most major towns and industries are situated in valleys on the larger streams and rivers. There are no sizeable reservoirs or lakes in the area of concern. Droughts are rare, but even in the most recent drought period (1959) low flow measurements were generally above 0.5 liters per second per square kilometer for watershed greater than 5 square kilometers.

SECTION A-4

WATERSHED MODELING

A-4.1 Occurrence of Surface Runoff

Most stream flow is due to surface runoff, however, this occurs only intermittently. The principal concern is the likelihood that radioactive contamination on the area will be transmitted to the water supply point (WSP). Contamination falling on all of the stream surfaces would arrive at the WSP within about five hours for most of the typical WSP watersheds. The average time for the contamination to reach the WSP would be approximately half this value, as the times developed in Table A-1 are based on the arrival at the WSP from the extreme point in the watershed. The area of running water in the small, typical watersheds would generally be much less than 1% (and possibly less than 0.1%).

There is a threshold of precipitation which will result in runoff. This threshold varies with season and recent rainfall. New England was used as the region of the U. S. which may be closest in character to that of the area of concern. The Appalachian area of Pennsylvania may also approximate the region and could similarly be used for estimating factors not immediately available for the German area. Rainfall and runoff records for New England have shown that as little as 0.15" (approximately 4mm) precipitation in the optimum season for runoff (February-March in New England and Germany, see Table A-2) may cause runoff, as noted in increased stream flow. A typical threshold would be about 0.25" (approximately 6mm), while 0.5" (13mm) may be necessary under very dry conditions in mid-summer (July and August, see Table A-2). Under an extreme drought condition 1.35" of precipitation did not produce an increase in stream flow.

Another factor in determining the occurrence and extent of storm runoff is recent rainfall. The specific factor used is the Antecedent Precipitation Index, which relates prior precipitation and the amount

of time since it fell. In summary, the saturation effect of prior rain is assumed to be reduced by a factor of ten percent each day. This factor and the seasonal variations are used with rainfall intensities and amounts to estimate stream flows.[A-2, A-3, A-4]

The general occurrence of rain in the region of concern was summarized in Table A-3. Daily precipitation records for several years for the area are given in Table A-5 through A-21. These data permit the determination of antecedent precipitation indices for individual days. Typical intensity of precipitation in the storms is indicated in Table A-22. Typical occurrence of snow as a component of precipitation is illustrated by Table A-23.

A simplified relationship for use in the runoff analysis for the area of concern is necessary due to the limited availability of stream hydrographs in which precipitation and subsequent stream flow can be directly correlated. Factors used for the simplified relation are those typically used, but developed from the various average data for the area.

An antecedent precipitation index (API) factor of 0.9 is typical for the eastern USA and has been recommended as an appropriate value for use in this study.[A-4] A threshold precipitation value for the occurrence of added surface runoff (the sum of the API and the day's precipitation) of from 4mm to 13mm was selected. These values are based on the experience in New England. The threshold-time-of-year relation selected is shown in Table A-24 and was based on the Fulda basin precipitation runoff audit, shown in Table A-2.

The extent of precipitation which results in surface runoff would be dependent on the seasonal surface permeability (partly reflected in the above threshold), the API, the short term intensity (e.g., Table A-22), and in winter seasons, the extent that the precipitation is snow (Table A-23) and the presence of snow cover (approximately mid-December to mid-March in the Fulda region, Table A-3). The data in Table A-23 indicates that most of the precipitation

Table A-5. Daily precipitation data (mm) - Bad Hersfeld (1972).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1		t		4.[illegible]		0.4	0.9	0.2	t			
2				[illegible]		3.7	3.0	t	0.8			
3	t		[illegible]	1.3	0.2		0.2	4.9				1.7
4	t	2.[illegible]	1.[illegible]	10.[illegible]	0.7		t	0.9			0.1	0.4
5	t			3.3	[illegible]			0.1			t	
6		0.4		3.5	t	5.5	1.1				0.3	
7		t	1.1	2.3	0.4	14.0			2.4		t	10.2
8	[illegible]	t	1.2	1.6	5.4	0.3	0.3	0.6			1.4	
9		t			11.2	2.3	28.6	9.2	t			0.1
10	[illegible]	1.4	5.9	4.6	13.5	0.4	8.3	2.5	17.9		5.2	
11	0.1	1.[illegible]	t	5.[illegible]	0.6	20.8		11.3			6.8	0.1
12		t			5.2	5.[illegible]			0.1		6.9	
13		0.2		0.9	0.5			0.1			3.4	
14		0.1		t				25.[illegible]			t	t
15				2.1	[illegible]	21.2		16.[illegible]			0.2	
16					13.3	1.[illegible]		[illegible]	9.3		t	
17								20.[illegible]	9.[illegible]		14.[illegible]	
18				2.0				0.9	[illegible]		t	nd
19	t			1.[illegible]		5.[illegible]		1.6		0.3	1.6	nd
20					t			t		0.0	[illegible]	nd
21	[illegible]			1[illegible]	t			0.6		2.[illegible]	1.[illegible]	[illegible]
22				[illegible]		[illegible]	[illegible]	[illegible]	0.[illegible]	t	[illegible]	[illegible]
23			t		[illegible]	[illegible]			t	[illegible]	[illegible]	[illegible]
24	0.4				[illegible]		17.[illegible]		[illegible]		[illegible]	nd
25	[illegible]			t	[illegible]		[illegible]	t	1.[illegible]			
26	[illegible]		3.[illegible]	[illegible]	[illegible]				[illegible]	4.3		
27			15.[illegible]	t	[illegible]				[illegible]	0.3	[illegible]	
28	t		[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]			[illegible]		
29	0.[illegible]		1.[illegible]		[illegible]	[illegible]	4.[illegible]					
30	[illegible]		t		[illegible]	[illegible]	[illegible]				t	
31	[illegible]		[illegible]		[illegible]		[illegible]					

Table A-6. Daily precipitation data (mm) - Bad Kissingen (1975).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.4	t						1.4	0.1		0.2	
2		0.1	0.1	6.3	0.7	1.4				1.3	0.2	15.3
3				10.7	6.6	1.3				2.4		4.3
4					t	1.9	1.7		0.9			
5	0.8				0.9				6.7	8.4		t
6	0.2		0.4	7.2	t					0.2		t
7	9.2		11.3	0.8	2.6						0.1	0.1
8	1.5			1.7	7.2							t
9					1.1	8.8				t	1.6	
10			3.5		t	0.6				3.6		0.2
11		t		0.7	1.3		6.5		2.4		2.7	
12	1.3		0.3	3.6			0.3		10.0	7.2	4.4	
13	1.9	1.6	0.9	2.2					10.8	13.4		0.6
14		0.9		10.6					8.4	0.4		t
15			0.8	7.8		5.3		t		t		
16			2.6	0.1	0.9	0.5		t			9.8	t
17	3.1	0.6		0.1		19.7	t	6.6		6.3		
18	4.7	9.0	t		2.5	16.2	12.1	0.7		1.5	0.1	
19	0.4	5.2	9.1	1.5		2.5	0.5	1.5		0.5	12.0	
20	0.7		1.2	1.0		0.0	9.3	2.4		t	3.3	
21	0.2					0.[illegible]	0.6	6.5			6.8	t
22	4.5					1.6	t	35.4			1.0	
23	3.2			t		0.1	0.2			t		t
24	6.0		1.1			0.5				t		1.[illegible]
25	9.6		3.5		t		5.8	0.5	0.2			3.[illegible]
26			6.[illegible]						4.5			t
27	9.2		6.[illegible]						0.5	0.2	0.2	
28	1[illegible]		0.1						0.6	0.1	4.3	
29	4.[illegible]			4.[illegible]	0.3					t	9.3	
30	1.5		t		3.1	t			2.0		2.3	
31	3.3							0.5				5.[illegible]

Table A-7. Daily precipitation data (mm) - Bad Kissingen (1976).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	16.3					9.0				0.2	0.4	2.2
2	11.5				0.1	2.6		0.6	5.7	2.2	4.6	10.2
3	3.4				5.3	3.3		1.6	0.2	0.3	1.8	0.6
4	2.5			2.5		0.5		0.1	0.8	15.6		1.5
5	7.9									t		2.5
6	6.3		0.1	t						0.5		9.3
7	t			0.9							7.9	7.3
8		t		0.3			5.8		t		0.3	7.5
9							t		13.6		2.0	
10	5.4	2.0				2.4		0.5	0.4		13.7	0.9
11	6.9	1.5			1.5						5.1	5.0
12	3.8	5.9	0.2		1.4			t	0.3	t		0.6
13	7.7	6.6			5.2		0.7	t	3.0	6.5		0.5
14	9.6	0.2		0.1			t		t	0.9	6.7	0.8
15	2.2		2.1						0.3		t	0.2
16	1.5		0.5						8.4	t	t	
17	0.2		4.7				1.4	t		1.1		0.3
18	t		1.8						t	0.5		t
19	2.3		0.4		1.0	t		0.3		1.0		
20	10.0				0.1		4.8			t		
21	7.6				0.7		0.4				t	0.2
22	9.6				0.3		t				0.1	0.1
23	10.6			1.6	t						1.5	t
24	1.9	2.4		3.9	12.1				0.5		16.3	
25	1.1	t	9.7	3.2			1.6				0.4	0.5
26			2.2		t		4.1		0.2			0.1
27	2.1			0.1	3.0			0.2	7.1		1.2	t
28							0.1		8.7	t	1.5	0.5
29		0.5			2.0				0.1		16.0	t
30			t	t	3.9			t	0.7	6.3	10.7	
31					2.0		0.8	0.3		0.3		0.7

Table A-8. Daily precipitation data (mm) - Bad Kissingen (1977).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	[illegible]			7.0				1.7		8.1		
2	1.7	t	0.2	t				t		7.5	18.1	
3	[illegible]	1.[illegible]	0.5	5.1		1.4				2.7	23.[illegible]	
4	t	4.[illegible]	3.8	1.6		t				5.2	1.[illegible]	
5		4.[illegible]		0.[illegible]	4.4	6.6				3.4		
6	0.7	6.[illegible]		[illegible]	2.[illegible]	1.1		17.7		[illegible]		5.3
7	[illegible]	1.[illegible]	1.6		0.7	[illegible]	t	14.[illegible]	2.2			0.[illegible]
8	4.9	2.[illegible]			[illegible]	9.[illegible]		2.1	5.5		0.[illegible]	
9	1.6	1.4		0.1					t	3.6	2.[illegible]	1.0
10	1.[illegible]	12.2		t	t	1[illegible]	0.[illegible]			11.5		0.3
11	1.9	3.[illegible]	t	1.6	1.3	[illegible]						2.6
12	[illegible]	[illegible]	12.[illegible]	4.[illegible]	4.4			1.8			10.3	16.9
13		1[illegible]	1.5	[illegible]	0.[illegible]	[illegible]	0.2	7.9				0.[illegible]
14	8.5		6.[illegible]	5.5		18.[illegible]	t	t			18.[illegible]	0.[illegible]
15	[illegible]	0.7	0.4	4.[illegible]	0.2	[illegible]		0.4	0.4		2.7	t
16	3.6	[illegible]		t	2.0	t		0.7			6.4	
17	t	[illegible]	t				0.1	32.3	0.2		8.4	
18		[illegible]	t			18.5	13.0	0.2	t		2.6	
19	4.[illegible]	[illegible]			[illegible]	9.[illegible]		8.3	0.6			
20	[illegible]	[illegible]	t		0.2	t	t	0.4	1.7		t	
21		[illegible]	t	t		2.2		6.5	2.3		5.[illegible]	
22	1.[illegible]	[illegible]		0.5		1.2		10.6	t	0.1	3.1	t
23	[illegible]	t		16.[illegible]				t			1.4	3.7
24		1.[illegible]		1.7			23.5			2.4	6.7	8.9
25	22.6	0.9		0.7		0.7	17.0	1.8			5.[illegible]	2.0
26	7.[illegible]	1.4	2.5	[illegible]		0.8	3.1	2.6			2.1	1.[illegible]
27	3.1	[illegible]	12.4			0.3	1.7	0.3		0.2	t	12.[illegible]
28	[illegible]		1.[illegible]	3.4			0.2		0.4	22.4	t	0.[illegible]
29	4.3		t	0.1		t						7.[illegible]
30	.3			3.4					0.9		0.[illegible]	8.[illegible]
31										7.6		4.[illegible]

Table A-9. Daily precipitation data (mm) - Frankfurt am Main (1975).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	t	0.9							0.1	0.1	4.1	t
2			1.7	9.9	2.6	0.9				1.6		7.5
3			0.1	11.5	1.4	6.5			7.9	0.2	0.1	1.8
4				0.6	1.2	1.4	28.8		8.6	1.4		
5			0.3	0.2			2.3		t	2.0	t	t
6	t		1.7	3.5	0.4						1.7	
7	7.6		6.2	0.5	8.9						0.4	
8			t	1.5	0.6		2.8				0.1	
9	0.1				1.1						t	
10	t		10.0	t		2.2			t	3.2		t
11		0.3		1.1	1.5		3.0	3.5	1.5		0.1	
12	0.3	t	0.1	0.7				2.2	12.9	1.3	3.9	
13	0.2	2.8	2.4	0.3	0.1				11.9	2.8		0.1
14	t		0.5	8.5	0.1				t	0.3		
15			0.3	20.2	0.1	5.6				0.1	2.7	
16	0.1		2.0		0.1	0.2		5.2			12.1	t
17	10.3	0.2	0.2	t		6.8		25.9		3.3	0.1	
18	3.2	9.1	t		2.5	12.0		0.3	0.9	0.8		
19	t	3.2	12.7	1.3		4.0		0.8	0.4	1.1	7.2	
20			0.2			1.5	15.4			0.2	0.1	
21	0.1	t				0.1	t	6.4			1.0	t
22	3.2					7.5		20.0				
23	7.2					0.3		0.1				
24			1.9			19.9	t					1.5
25	7.2		t		t		t	3.7	1.9	0.2	t	0.8
26	0.2		4.1						3.0	0.1	1.1	t
27	8.5		9.2						0.2	0.1	1.5	
28	10.3		0.1						3.2		2.6	
29	4.6				7.5	1.5					3.1	t
30	0.1		0.4	t	1.3	0.5			5.2	0.1	1.6	
31	1.2							7.4		t		1.6

Table A-10. Daily precipitation data (mm) - Frankfurt am Main (1976).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	5.1					10.1				0.9	1.0	5.3
2	3.8				0.2	t		0.2	8.5	2.7	3.1	4.6
3	2.2			0.3	4.4	0.9		0.6		0.5	1.8	0.4
4				7.5				0.2	0.9	2.1		5.2
5	1.9			0.1								0.4
6	0.7								t	0.9		6.4
7	0.1			1.1			0.5		t		9.2	4.5
8									1.0	t	1.2	3.0
9								t	7.5		3.5	t
10	2.8	2.3				0.1		t	t		1.3	1.1
11	1.9	0.7			1.4				0.4		3.8	0.6
12	0.8	17.6	2.0		2.3				0.3	0.9		0.4
13		3.9	0.5		2.9		3.6	0.4	0.4	6.9		0.4
14	0.7	t		t					2.0	1.5		0.8
15	1.0		2.4						5.2		0.3	
16	1.5		1.2						3.7			
17			5.7				18.8		t	1.8	t	
18	0.3		0.6					1.6		0.2		t
19	2.7		0.2		0.6					1.9		
20	4.4				0.4		19.9			0.1		
21	0.2	t			3.6		4.9			0.1		
22	1.2				0.2		0.5				1.2	
23	1.8			1.8							0.5	t
24	0.2	1.9	t	11.5					0.2		0.6	
25	2.8	t	1.2	0.8			3.7			0.1	0.4	t
26	0.5	t	0.4		0.2		1.6	0.5	0.3	0.1		0.1
27	0.9	t			0.8			0.3	1.8	t	1.4	
28		t						0.3	2.8	0.2	2.1	0.6
29								0.2	t	t	8.3	
30					2.1					6.6	12.1	
31					2.0		2.9			t		t

Table A-11. Daily precipitation data (mm) - Frankfurt am Main (1977).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	[illegible]		0.5	2.3	0.6					3.0	3.2	t
2	5.7		0.4	2.5						1.3	17.5	
3	t	2.4	0.2	7.0		t			0.2	0.3	12.5	
4		7.6	0.4	1.4	t	1.5				4.5	2.4	
5	0.1	1.0			1.6	4.9				16.0		
6	0.4	4.9		t		0.6						7.7
7		3.3	1.1		7.2	3.6		8.2	0.3	0.1		0.6
8	0.3	0.2	t		3.1	3.2		0.3	9.0		0.1	0.9
9	5.1	4.5				2.0				1.3	1.4	0.7
10	[illegible]	9.6		t	0.1	4.6				0.1	0.1	
11		1.8	1.7	0.8	4.9							3.6
12		11.8		1.9	5.8		0.1	3.4			4.4	12.3
13	4.1	0.3	1.4	1.8		1.3	2.8	40.2			0.8	0.1
14	3.1	0.1	4.2	1.5		1.1		0.2			8.6	0.3
15	1.3	5.2	0.2	0.5	2.1	5.2					3.0	0.1
16	t	[illegible]						2.2			6.2	t
17		[illegible]	4.0			0.7		22.2	0.1		0.1	t
18		[illegible]	2.7			5.4	6.7	0.2	0.4		t	
19	2.1	[illegible]			1.9	3.5		31.6				
20		[illegible]			0.6	0.9	4.1	12.9	0.8		0.5	
21		[illegible]	1.1	0.5			t	8.3			5.0	
22	4.2	t		2.1		0.1	t	24.0		0.1	1.3	t
23	[illegible]			11.6				3.0			5.0	5.4
24	1.1	2.4	t	t		0.7	20.2			2.1	1.2	1.1
25	[illegible]	[illegible]	t	0.3		11.0	6.6	3.6	0.2	7.2	1.7	t
26	[illegible]	t		0.4		4.3	7.6	1.3			t	2.3
27	[illegible]	[illegible]	11.7			2.7		0.9		0.2		6.9
28			t	[illegible]						9.8		0.5
29	0.5					4.6	1.1			0.1		2.1
30				0.1			0.8		2.4			3.7
31			3.0							7.2		0.1

Table A-12. Daily precipitation data (mm) - Frankfurt am Main (1980).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	t	t	t	0.2		t	1.3	No		t		
2		1.3	t	0.3	0.4		0.3	Data				0.2
3	t	2.0		t	1.2		0.1	for			t	0.1
4	0.8	1.4	t	t	0.1			Month	t		t	t
5	0.1	0.6					t		0.3		t	0.7
6	0.1	0.2	0.9		0.1	0.8	0.2			0.2	t	t
7	0.2	0.1	0.2	t	t	0.5	0.7			0.9		
8		t		0.1	0.3		0.2		1.2	0.3		t
9	t		t	0.1		0.4	0.1		0.3	0.7		
10		0.1	0.4	t		0.2	0.5		0.2			
11	t	0.1	t				[illegible]		t	0.2	t	t
12		t	0.5				[illegible]		0.3			
13		0.1	0.1			t	0.2		0.1			0.8
14						1.0	1.5				0.5	[illegible]
15		0.3				t	0.3			0.2	0.7	0.3
16		t				t	t			0.3	1.1	
17						0.1	t			0.6	0.2	0.3
18				t		t	0.2				t	0.4
19			t	t		0.1	0.6			0.2	0.1	
20	t		t	0.1		0.1	[illegible]					0.7
21	0.7		0.2	0.1	t	t			t			
22	0.3		0.1	t		0.4				t		t
23	0.6					t				0.5		0.1
24	t			0.3		1.3			0.1	0.9		
25	0.1		0.1	1.2		0.2			0.1	t	0.6	0.1
26	t		0.9	0.1		0.4						t
27	t		0.5	0.1	0.4	0.1			t	t	0.1	t
28			t			1.0			t	t	0.3	
29	t	t	0.2	0.1	3.5	t	0.2			0.1	0.2	t
30	0.6	t	t		0.1	0.3	t			t	t	t
31	1.0	t	0.8		0.2							t

Table A-13. Daily precipitation data (mm) Fulda (1975).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	[illegible]	[illegible]		t	t	t		[illegible]	[illegible]	[illegible]	1.7	
2	[illegible]	[illegible]	0.7	2.3	[illegible]	[illegible]			0.6	1.3	0.1	9.4
3				4.4	5.4	1.4			0.3	1.6		2.6
4			t	t	0.6	[illegible]	t		9.7	0.9		0.1
5	[illegible]				t				t	6.1		0.4
6	[illegible]		t	[illegible]	t							
7	[illegible]		6.3	1.7	4.1						t	0.2
8	[illegible]	t		[illegible]	[illegible]		t					t
9				t	t	3.9					1.1	
10			[illegible]	t		2.5				0.9	t	t
11		t	t	1.2	4.2		6.9	t	1.1		3.1	
12	[illegible]			2.3			0.5		9.6	6.4	7.1	
13	[illegible]	[illegible]	[illegible]	[illegible]					7.5	11.2		[illegible]
14		[illegible]	2.5	3.8			33.7		[illegible]	1.2	0.4	
15			[illegible]	11.2	t	4.3	t	[illegible]		0.6	1.5	
16			[illegible]	1.7	t			1.3			2.8	
17	[illegible]	[illegible]	[illegible]	t	[illegible]	24.9		[illegible]		4.1		
18	[illegible]	[illegible]	[illegible]	0.1	4.8	22.0	[illegible]	[illegible]	3.6	0.7	0.1	
19	[illegible]	[illegible]	5.4	[illegible]		3.3		0.2		0.3	7.5	
20	[illegible]		2.4	0.2		3.8	9.4	[illegible]			4.8	0.1
21	[illegible]						0.4	[illegible]	[illegible]		3.3	t
22	[illegible]					[illegible]		[illegible]	t	t	0.5	
23	[illegible]					0.1		[illegible]		t		
24	[illegible]		1.4			14.3	0.8	[illegible]				[illegible]
25	[illegible]		0.3		0.2		4.9		2.9	t		[illegible]
26			5.1						15.0	t	t	
27	[illegible]		[illegible]						0.6	0.1	1.6	
28	6.4		1.0						1.3		3.0	t
29	[illegible]				0.8	0.7			t		8.1	t
30	[illegible]		[illegible]		[illegible]	0.9		0.1	[illegible]	t	1.7	t
31	[illegible]							[illegible]				[illegible]

Table A-14. Daily precipitation data (mm) - Fulda (1976).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	11.6					19.3		0.1	2.4	0.2	0.5	t
2	13.2				0.2	2.1		1.3	5.9	3.4	1.1	3.0
3	8.0			t	1.9	4.9		3.8	0.3	0.1	1.6	t
4	t			5.9		0.5			0.2	9.7		1.6
5	5.6											1.0
6	1.2			t						0.2		5.8
7	0.2			2.5							7.6	5.0
8	t	t		1.5					t		1.0	3.1
9	0.2		1.8			t			6.6		1.1	0.8
10	3.1	2.3						6.6			1.0	0.8
11	3.1	1.8			3.1						5.5	4.7
12	0.3	4.3	t		1.1			1.8		t		0.5
13	2.6	1.5	0.1		3.9		25.3	0.1	1.1	7.5	0.1	0.4
14	4.9	0.2	0.1	t				0.8	0.6	0.1	0.3	2.1
15	4.4		1.6						0.3		0.3	0.3
16	0.9		1.5								t	t
17	0.2		3.2				8.1			2.3		
18	t		0.7					t		0.2		t
19	2.2	t	1.4		10.1	t		3.2		0.1		
20	8.4				0.2	t		4.9		t		
21	3.1				5.9		4.4				0.3	
22	5.6						1.4				2.0	t
23	3.6										0.4	t
24	0.7	0.5	t	5.2					t		2.3	
25	4.2		2.1	1.0	0.8		1.0		t		0.8	0.2
26			8.3		0.7		1.0	t	1.0			t
27	1.0		0.2	0.7	1.3			6.8	3.0		0.2	
28				t				0.2	3.1	0.1	1.0	1.0
29		0.2			1.8				0.2	0.1	8.7	
30				t	0.9			t		0.9	15.1	
31					2.2		5.6	t				t

Table A-15. Daily precipitation data (mm) - Fulda (1977).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.3			6.3				1.9		7.3		
2	3.8		0.7	t						0.5	11.3	
3	0.7	1.1	0.4	3.4		1.0			0.2	1.5	31.2	
4	t	2.7	1.6	1.4	t	0.7				3.1	4.0	
5		1.3		t	3.4	8.7				14.6	t	
6	1.6	1.9		3.0		0.6		1.2				3.4
7	0.1	7.0	1.7		0.3	2.5	0.1	18.[illegible]	2.8			t
8	3.8	t		1.5	0.6	0.2		0.3	6.7		0.6	
9	2.0	0.2		t		6.6			0.3	3.7	0.4	1.1
10	9.0	5.0		t		9.0			t	3.4	t	
11	0.3	2.2		1.1	t			t	t			0.8
12	3.4	2.8	2.1	3.0	5.2			1.0			13.5	8.7
13		3.1	0.5	4.0	3.6	2.[illegible]	6.3	0.2			0.7	0.6
14	4.1		7.0	2.7		16.2		0.5			14.3	t
15	1.6	0.3	1.4	2.3	0.6	5.5	0.2	0.6	0.2		5.5	0.4
16	2.8	0.[illegible]	t	0.2	10.3	0.1					2.5	
17	0.2	2.8	0.2				0.6	23.7			2.1	
18		2.5				10.2	6.4	0.3			1.4	
19	3.2	13.8			13.2	8.4		10.7			0.7	
20	t	29.0			1.0		1.9	3.3			t	
21		1.6	0.3	t				6.1	0.2		4.0	
22	2.4	t		0.4				5.0		0.3	0.6	
23		0.2		14.8			t			0.1	6.7	1.1
24	0.2			1.3			30.4			7.0	9.9	0.7
25	6.6	1.3		0.8		2.3	4.4	3.2		t	3.7	2.7
26	1.8	2.7	5.6	0.9		9.9	1.2	0.9		t	0.7	2.1
27	2.6	0.6	11.5				t			t	0.5	6.[illegible]
28			3.5	1.1		t	t		t	18.1		0.3
29	2.4		t	0.1		3.9						3.9
30				2.5					1.5		0.9	3.4
31			t				t			6.6		1.2

Table A-16. Daily precipitation data (mm) - Giessen (1972).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1		[illegible]		6.1		0.6	3.4	t				0.1
2				0.3		2.1	1.1	t				
3		1.1	1.0	8.4	0.1		t	1.5				4.2
4		1.2	6.0	6.7	0.6						0.6	
5	0.5			2.5	t	1.0					0.1	
6		0.2		2.3	2.4	14.2					0.1	
7		0.2	t	3.6	0.6	14.9		0.1	0.3		t	6.2
8	3.0	0.6	0.2	0.7	0.6	t	0.1	t			0.8	
9		0.1	0.3		9.9	4.1	47.5	11.1	0.4			0.1
10		0.6	6.3	3.9	6.6	t	0.8	0.3	28.0		4.6	t
11	3.5	2.9	0.3	0.1		7.1		6.8			4.4	
12	0.2				6.1	0.1		t			13.7	
13	0.2				5.0			1.1			3.4	0.3
14				1.3				23.9			2.2	
15				7.4		0.5	t	5.7			0.3	
16					17.2	0.2	t	5.0	3.9		1.3	
17					0.7			17.5	1.5		27.9	
18				2.3		0.1	3.3	3.9	1.1		t	nd
19	1.0			0.2		1.2		t		0.3	4.5	
20	0.8			0.3	0.5			[illegible]		1.0	4.7	[illegible]
21	1.0			5.4	0.3	t		1.7		0.3	[illegible]	nd
22				2.8		5.2	0.1	[illegible]		1.3	0.6	nd
23					5.8	2.3				0.6	0.4	nd
24	2.5				1.1		29.7		0.7			nd
25	3.2				3.8							
26	2.4		2.5	0.3	9.4				1.9	3.3		
27	0.1		10.3	0.1	6.6				0.3	1.7		
28			2.5	0.3	6.3	4.9				3.7		
29	0.1		2.9	t	4.3	19.4						
30	0.4				1.2	9.5	t				0.6	
31	0.1		1.9		t		2.9					

Table A-17. Daily precipitation data (mm) - Giessen (1975).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	t	0.4		t		t		1.4			6.2	
2			1.1	12.1	5.6	2.4				3.9		7.7
3			0.1	12.6	1.5	2.7	t		1.3			1.0
4			t		2.2	0.4	0.3			4.2		t
5	t		0.5		3.7				0.5	1.0		0.2
6	0.2		0.6	5.1	1.3					0.9	1.3	
7	5.2		4.0	2.1	4.0				0.3		0.3	0.8
8				0.9	4.0		3.4					t
9	t										0.1	
10			6.2	0.1	1.0	3.7			4.2	0.2		t
11		0.4	t	0.6	2.3		3.4		0.3		0.4	
12	0.3		0.8	0.9					5.0	6.1	2.3	
13	t	2.1	1.0	t					7.7	7.2		1.7
14		0.7	6.2	14.6	1.2				0.5	1.0		
15		0.1	0.8	7.5	0.8	3.0		t			0.5	
16			0.9	1.3	0.7			t			8.0	t
17	1.3	0.2	1.0	0.6	15.4	12.7	0.3	6.6		4.3		
18	2.3	15.2	0.4		2.6	10.1	t	0.7	4.0	0.3	0.3	
19	0.1	1.4	8.5	2.9		0.2	t	1.5		0.5	3.6	
20			0.7	0.1		0.9	26.4	2.4			0.2	0.2
21	t					4.6	2.0	6.5			1.1	0.1
22	5.4					t		35.4				
23	0.6						t					
24			2.7			2.8	0.4					2.0
25	7.6		1.1		0.6		3.0	0.5	5.3		0.1	1.5
26	0.9		2.3		0.1				7.7		3.1	
27	11.9		8.7						0.9	0.1	1.5	
28	6.3		0.6						2.3		2.3	
29	1.3		t		2.8	0.7					4.1	
30	1.5			t	0.5	0.6			6.7		1.0	
31	4.5						0.5					1.7

Table A-18. Daily precipitation data (mm) - Giessen (1976).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	9.7					16.6				0.7	4.6	t
2	4.3				t	0.2		3.9	3.3	1.2	3.1	6.[illegible]
3	3.8			t	1.9	0.4		0.6			0.9	t
4	1.3			2.5				t	0.4	0.7		0.7
5	5.2											0.1
6	0.8		t	t						2.4	0.3	1.5
7	0.2			1.0							5.7	1.1
8		t							2.4		0.1	2.4
9	t		0.9			0.5			9.6		3.1	0.1
10	2.0	3.2				0.6	t	0.3	t		1.0	0.7
11	1.1	1.1						2.3	0.2		5.1	1.0
12	1.9	4.1	0.4		2.5		0.3		1.0	1.1		0.7
13	0.8	2.8			1.7		0.6	7.3	0.3	8.0		0.6
14	5.7	t					t		t	1.8	t	0.5
15	0.8		2.0						8.0		0.1	t
16	0.6		t						0.5			
17	0.5		4.3				10.5			9.7		t
18	t		0.1		t					1.3		0.2
19	0.2				0.2					4.0		
20	7.2				3.4	1.1	8.6					
21	1.2				3.5		3.0			t	t	t
22	5.5						3.6				1.3	
23	4.3										0.7	
24	0.6	2.6	t	2.1	t		0.3		t		1.3	
25	t		0.3	t	t		0.9				t	t
26	0.3		7.7		1.7		t	3.1	0.1			
27	2.9				0.2			1.2	8.1	0.2	0.7	t
28								0.7	5.6	0.6	0.5	1.4
29		0.5	t		t			t		t	6.5	
30			t		t					2.4	10.5	
31					1.7		6.9	0.5				1.0

Table A-19. Daily precipitation data (mm) - Giessen (1977).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	9.3		t	4.9	0.1			1.0		4.3		
2	9.8		0.5	1.0		t				3.2	17.2	
3	0.5	1.9	0.1	3.9		t			0.5	2.8	52.7	
4	1.3	3.9	1.0		1.1	0.4				2.6	3.4	
5		1.6			8.3	5.9				17.0		
6	1.9	2.1		1.8		4.1				1.0		8.2
7	t	7.8	1.7	0.1		5.8		5.6	0.4			0.1
8	0.4	0.7		t	3.9	0.7		1.3	3.4	0.2	1.7	1.6
9	3.4	1.6			t	7.2			0.2	1.5	2.5	1.6
10	1.1	6.7		t	t	12.9	t			0.5		
11		0.1	t	0.9	1.7			t			0.7	2.9
12		5.7	t	1.1	3.1			7.1			12.4	16.7
13	1.0	2.4	0.6	1.6	0.1	2.7	1.3	2.5			0.5	0.9
14	4.0	t	6.9	2.1		8.5					14.6	1.5
15	2.4	4.0	0.2	2.7	1.0	9.7			t		3.0	0.8
16	1.0	0.8		t	1.4	t			t		1.7	
17	t	7.8	4.7			t	1.9	22.7	t		0.7	
18		4.5	0.4			34.2	11.9	0.4			t	
19	1.0	12.8	0.9		6.6	0.5		10.3			t	
20	0.1	20.3		0.1	0.9		3.4	3.7	0.4		0.3	
21	0.7	0.1	1.9	0.2			t	10.4		t	1.4	
22	3.0	0.7		0.1				4.9		0.4	1.5	0.3
23	0.2	0.1		9.0			0.2	0.1		t	5.4	2.5
24	1.0	0.5		0.8			26.4			0.3	3.2	3.1
25	13.[illegible]	4.1	0.1	0.5		4.8	13.1	9.4			2.3	0.4
26	3.0	0.1	0.2	t		0.3	4.7	1.0	1.2		0.2	1.6
27	2.1	0.8	10.1			0.1	t	t			0.2	6.6
28			0.1	0.3		t	t			4.3		1.8
29			t			5.3	1.9					2.4
30				0.1					4.5		t	6.0
31			0.2							5.2		0.8

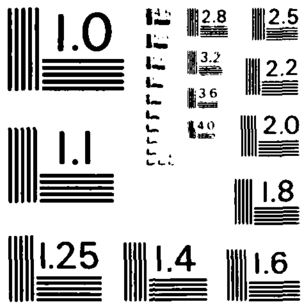
Table A-20. Daily precipitation data (mm) - Neukirchen-Hauptschwenda (1980).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.[illegible]	0.4	t	0.8		0.4	1.4		t	0.1		
2	0.1	0.5	0.3	0.1			1.9				t	0.5
3	t	0.8	0.2	0.5		t	0.5	0.9			t	0.[illegible]
4	0.5	0.5	0.2	0.1			0.4				t	0.4
5	0.2	0.6		t			0.2	t	0.4	t		0.9
6	0.2	0.6	0.4		t		0.1		0.1	0.4	1.0	0.2
7	t	0.1	0.2	0.1	0.1	1.6	1.1			1.4	0.2	
8	t	t	0.1	0.4	0.3		0.1	0.1	1.2	0.2	t	t
9	t			1.0		0.5	0.2	t	0.5	0.2		
10	t	t	0.2	0.1		3.5	0.6		0.2			
11	t	0.3	0.1			0.1	0.9	0.7	0.6	t	0.1	0.1
12	t	t	0.4			t	0.4	0.4	0.1		0.2	
13		t	0.2			t	0.2		1.0	t	t	0.6
14						1.4	0.2		0.2	t	0.1	1.0
15	t	0.2				1.5	0.8		t		0.9	0.[illegible]
16	t	[illegible]				0.2	t			0.2	0.5	t
17						0.7	t	t	0.5	0.3	0.7	0.[illegible]
18		t	0.2	t	t	0.1	0.2				0.[illegible]	1.[illegible]
19			0.[illegible]	0.5		0.6	1.1	0.2		0.1	0.3	
20	t		t	0.3	t	0.4	1.6	t				0.2
21	0.2		0.1	0.1		t	2.6	0.2				0.1
22	0.1			t		0.3		1.0		t		0.2
23	0.2		t		0.3	0.4		0.1	0.1	0.1		0.1
24				0.9	0.1	0.6		0.2	0.3	0.3		t
25	0.3		0.2	1.8		0.4			0.1	0.1	1.5	0.1
26	[illegible]		[illegible]			0.5				t	t	0.5
27	0.[illegible]		0.4	0.5	1.[illegible]	0.1				0.1	0.2	0.1
28	0.1	t	0.4	t	t	1.2	t	t		0.1	0.5	
29	0.1	0.4	0.5	0.1	3.2	0.7		0.5		t	1.0	t
30	0.5		0.1		0.3	0.1	t	0.[illegible]	t		0.1	0.[illegible]
31	[illegible]		0.[illegible]		0.2			0.2	t	t		0.3

AD-A131 425 NUCLEAR WARFARE WATER CONTAMINATION(U) SCIENCE APPLICATIONS INC SCHAUMBURG IL J C PHILLIPS ET AL. 01 MAY 82 DNA-TR-81-127 DNA001-81-C-0234

2/3

UNCLASSIFIED F/G 15/6 NL



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

Table A-21. Daily precipitation data (mm) - Schotten (1980).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.4	0.3	0.1	0.5		0.1	1.9			t		
2	0.1	0.9	0.1	0.2			1.6			t		0.7
3	t	1.8	0.1	0.1	1.8	0.1	0.3	0.4				0.3
4	1.0	0.8	0.1	0.1	0.1		t		t			0.9
5	0.4	0.5					0.2		0.6		t	1.5
6	0.6	0.7	0.7		0.3		0.3		0.3	0.6	0.5	0.1
7	0.1	0.2	0.1	t	0.1	0.1	0.6			1.9	t	
8		0.1		0.1	0.6		0.1	0.1	1.6	0.3		0.1
9	t			0.4		0.2	0.4		0.3	0.2		t
10		0.2	0.4	0.2		1.2	2.5		0.4			
11		0.3	0.1			0.1	1.5	0.9	0.4	0.2	0.2	0.2
12		t	0.7				0.6	1.0	1.0			0.1
13		0.1	0.1				0.9		0.3			1.7
14						1.3	0.7		0.4		0.5	1.0
15			0.8			0.2	1.1			t	1.2	0.2
16			0.2			0.3		1.8		0.2	1.6	
17						0.7			0.1	0.4	0.3	t
18				t		0.4	1.2			t	0.1	1.1
19				0.4		0.6	1.3	0.6		0.3	0.2	
20				0.1		0.6	1.7					0.5
21	0.3		0.2	t		0.1	1.8	0.5				t
22	0.2		t	0.1		0.4		0.1		t		0.2
23	0.7					0.2		t		0.8		0.7
24	0.1			0.9		0.8		t	0.2	0.8	t	0.1
25	0.2		0.2	2.2		0.6			0.2	t	1.2	0.6
26	0.2		0.6	t		t						0.1
27	t		0.9	0.6	0.4	0.3	1.5			0.1	0.5	t
28	0.2		t			1.2				t	0.7	
29	0.1		0.3		2.0	0.2		1.0		0.4	0.5	0.1
30	1.2	t	0.1		0.7	0.1	0.3	0.9			0.1	0.2
31	1.2	0.2	1.2		0.5			0.5				0.3

Table A-22. Frequencies of instantaneous (4 min) precipitation rates of Frankfurt am Main.

Specified Rate (mm/hr)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.25	4.65	4.35	4.40	5.30	6.05	6.65	6.15	7.05	6.30	6.55	5.25	4.50
1.0	2.18	1.95	1.91	2.25	2.87	3.20	2.88	3.51	2.64	2.74	2.40	2.24
2.0	0.95	0.83	0.79	0.89	1.38	1.72	1.39	1.74	1.05	1.11	1.21	1.11
3.0	0.48	0.41	0.38	0.37	0.73	0.93	0.74	1.01	0.48	0.51	0.70	0.65
4.0	0.27	0.23	0.21	0.23	0.43	0.59	0.46	0.67	0.28	0.28	0.43	0.41
5.0	0.18	0.15	0.13	0.14	0.29	0.41	0.32	0.47	0.18	0.19	0.28	0.27
10.0	0.06	0.05	0.04	0.04	0.09	0.15	0.10	0.16	0.05	0.06	0.07	0.08
15.0	0.03	0.03	0.02	0.02	0.04	0.07	0.04	0.08	0.02	0.03	0.03	0.04
20.0	0.01	0.01	<0.01	0.01	0.02	0.04	0.02	0.04	0.01	0.01	0.02	0.02

Table A-23. Percentage of frequencies of occurrence of mixed precipitation at Fluda.

Hours (LST)	Thunder-storms	Rain and/or Drizzle	Freezing Rain and/or Drizzle	Snow and/ or Sleet	Percent of Observation with Precipitation
Jan					
00-02	0.0	7.7	0.5	12.1	20.3
03-05	0.0	13.8	0.7	10.8	25.3
06-08	0.0	17.0	0.4	10.7	28.0
09-11	0.0	15.3	1.6	9.1	25.7
12-14	0.0	13.3	0.9	8.6	22.8
15-17	0.0	12.1	0.6	8.5	21.2
18-20	0.0	11.0	0.5	14.3	25.8
21-23	0.0	5.4	0.0	19.4	24.7
Totals	0.0	13.7	0.8	10.2	24.6
Apr					
00-02	0.0	14.8	0.0	2.8	17.6
03-05	0.0	14.2	0.0	3.3	17.2
06-08	0.0	14.0	0.0	4.1	17.7
09-11	0.0	14.7	0.0	3.5	17.6
12-14	0.5	12.6	0.0	2.1	14.7
15-17	0.4	15.5	0.0	1.7	17.1
18-20	0.6	11.9	0.0	1.7	14.1
21-23	0.0	10.0	0.0	3.3	13.3
Totals	0.2	13.9	0.0	3.0	16.7
Jul					
00-02	0.6	3.3	0.0	0.0	3.9
03-05	0.3	4.8	0.0	0.0	5.0
06-08	0.3	7.7	0.0	0.0	7.7
09-11	0.5	6.8	0.0	0.0	7.1
12-14	1.8	6.3	0.0	0.0	7.4
15-17	2.0	6.6	0.0	0.0	8.1
18-20	2.2	3.4	0.0	0.0	5.1
21-23	0.0	3.2	0.0	0.0	3.2
Totals	1.0	6.1	0.0	0.0	6.7
Oct					
00-02	0.0	12.3	0.0	0.0	12.3
03-05	0.0	13.0	0.0	0.3	13.2
06-08	0.0	11.9	0.0	0.0	11.9
09-11	0.0	10.1	0.0	0.0	10.1
12-14	0.1	11.5	0.0	0.3	11.6
15-17	0.4	12.5	0.0	0.4	12.6
18-20	0.0	9.5	0.0	0.0	9.5
21-23	0.0	10.8	0.0	0.0	10.8
Totals	0.1	11.6	0.0	0.2	11.7

Table A-24. Cummulative precipitation necessary for added surface runoff.

Month	Threshold (mm)
January	8
February	4
March	5
April	9
May	12
June	12
July	13
August	13
September	12
October	12
November	10
December	9

in the area occurs as rain, even in mid-winter. The precipitation-runoff audit, Figure A-1, shows that snow cover has little inhibiting effect on runoff, the fraction of precipitation which becomes surface runoff being greatest in the winter months. Snow cover may have a delaying effect upon when the actual precipitation enters the streams, however, as the surface runoff would consist of both melted snow from prior precipitation and recent rainfall.

The single seasonal precipitation-surface runoff ratio selected to be used for this study is shown in Table A-25. The relationship is an approximation as the proportionality would actually be a function of intensity and total precipitation in the individual storm. The entries in Table A-25 were estimated by considering the general frequency of precipitation sufficient to directly increase surface runoff (about 1 per month in winter to 2 per month in summer, Table A-13), the average rainfall in the month and the average surface runoff (Table A-2), and subtracting the thresholds (Table A-24) from the precipitation.

The factors developed above can be used to provide a rough approximation of surface runoff which might occur following a given level of precipitation on a day of a given month, with the additional data of recent prior daily precipitation. This relationship is shown below:

$$SRO = [SRO/P_e] \times P_e$$

with $$P_e = P_o + API - CPT$$

and $$API = \sum P_{o-n} \times (0.9)^n$$

where SRO = surface runoff (mm)

$[SRO/P_e]$ = surface run-off excess precipitation ratio, given in Table A-25

P_e = excess precipitation (mm)

P_o = 24-hour precipitation (mm); given in Table A-13

API = antecedent precipitation index

Table A-25. Estimated proportion of excess rainfall which becomes surface runoff.

Month	Surface Runoff/Excess Rainfall
January	0.45
February	0.65
March	0.58
April	0.34
May	0.11
June	0.10
July	0.13
August	0.10
September	0.12
October	0.16
November	0.40
December	0.42

CPT = cumulative precipitation threshold (mm), given Table A-24

P_{o-n} = 24-hour precipitation n days before the day of P_o (but if $P_{o-n} > CPT$ use $P_{o-n} = CPT$, to avoid double counting of prior precipitation that resulted surface runoff), as given in Table A-13.

The above expression provides the possibility of double counting 24-hour precipitation below the level of the CPT which occurred prior to both the current storm and an earlier storm which resulted in excess precipitation. Further refinement of the expression, however, does not appear justifed in view of the assumptions and approximations associated with the factors it contains.

Application of the expression is illustrated by the following example.

Problem: Determine surface runoff (SRO) from a watershed in the Fulda river basin region due to the storm of 14 July 1975.

Solution: $[SRO/P_e] = 0.13$ (Table A-25)

CPT = 13 mm (Table A-24)

$P_o = 33.7$ mm (Table A-13, 14 July)

API = $[.5 \times .9^2]$ + (Table A-13, 12 July)

$[6.9 \times .9^3]$ + (Table A-13, 11 July) (prior precipitation ignored)

API = 5.4 mm

$P_e = 33.7 + 5.4 - 13 = 26$ mm

SRO = 0.13 x 26

SRO = 3.4 mm

If the watershed area is 10 Km^2, the surface runoff passing the water point resulting from the precipitation on July 1975 would be:

$$(3.4)\text{mm} \times (10)\text{km}^2 \times \left(\frac{1}{1000}\right) \frac{\text{m}}{\text{mm}} \times (1000)^2 \frac{\text{m}^2}{\text{Km}^2} = 34000\text{m}^3.$$

A-4.2 Time Factors in Surface Runoff

The expression developed above does not indicate the time, following the occurrence of precipitation, when the surface run-off would pass the point of exit of the watershed (that is the water supply point). This time is a function of the size, shape, and average slope of the watershed; surface conditions (time of year); and the parameters of the storm itself.

This study is primarily concerned with small watersheds (Table A-1) with negligible surface storage. Surface runoff resulting from rain on the watershed which exceeds the cumulative precipitation threshold (Table A-24) would start to arrive at the water supply point (WSP) immediately from the area draining immediately upstream. The amount arriving from a continuing rainfall would increase rapidly until the "time of peak flow" was reached, which corresponds to the longest time that it takes runoff originating anywhere on the watershed to arrive at the WSP. Snyder's Synthethic Procedure can be used to develop this longest time (also referred to as the "time of concentration").(A-5) In this procedure the time is related to the watershed's relief, shape, and length by the following expression:

$$t_p = C_T \cdot (L \cdot Lc)^{0.3}$$

where

t_p = time of concentration (hr),

C_T = constant,

L = length of watershed (miles), and

Lc = distance from the center of gravity watershed to the watershed outlet (water point) (miles).

Values of C_T (see Table A-1) are based on those for the Appalachian Mountain regions, modified for the relative average steepness of the watershed slope. The calculated values of t_p are shown in Table A-1.

The rate of runoff, from rain falling at a uniform rate and considering such factors as velocity of sheet and stream flow, would increase with time as the ground absorbed less of the precipitation and flows became greater. As a result, the amount of flow at the WSP would continue to increase beyond the time of concentration ("time to peak flow"), at least until the precipitation rate reduced.

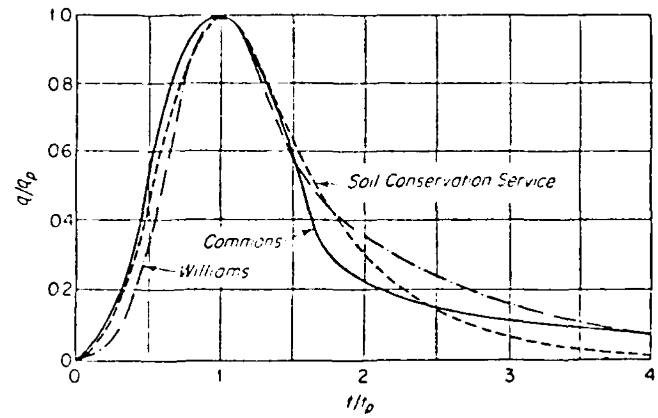
The flow of surface runoff following a rainfall decreases approximately exponentially. This is illustrated for typical streams in Figure A-2, and some specific rivers in Figure A-3. The gradual reduction in flow following heavy rain for points in the Fulda River basin is shown for three cases in Figures A-4, A-5, and A-6. Note that the stream records are in terms of gauge height. The precipitation records are cumulative, thus the periods of most intense rainfall are where the precipitation curves have the greatest slope. Figure A-4 shows the results of one winter storm, Figures A-5 and A-6 illustrate stream heights during and following two successive storms.

In consideration of the above and the relatively small areas of the WSP watersheds (Table A-1), it may be assumed that surface runoff occurs essentially within four days of the rainfall. An assumed distribution of this flow is: first day, 38%; second day, 44%; third day, 11%; and fourth day, 7%. To approximate flows from successive days of excessive precipitation, the flows can be accumulated. For convenience of analysis in this effort, the flow may be assumed to be distributed over the entire 24 hours. Thus surface runoff of 1 mm in one day would be equal to a flow of:

$$(1)\quad \frac{\text{mm}}{\text{day}} \times \left(\frac{1}{86400}\right) \frac{\text{day}}{\text{sec}} \times \left(\frac{1}{1000}\right) \frac{\text{m}}{\text{mm}} \times (1000)\ \frac{\ell}{\text{m}^3} \times (1000)^2\ \frac{\text{m}^2}{\text{Km}^2} = 11.6\ \frac{\ell/\text{sec}}{\text{Km}^2}$$

The approximate total flow would be the combination of ground water runoff for the corresponding month (Table A-2) and the surface runoff caused by the precipitation.

Some Dimensionless Unit Hydrographs



Schematic Diagram of the Disposition of Storm Runoff

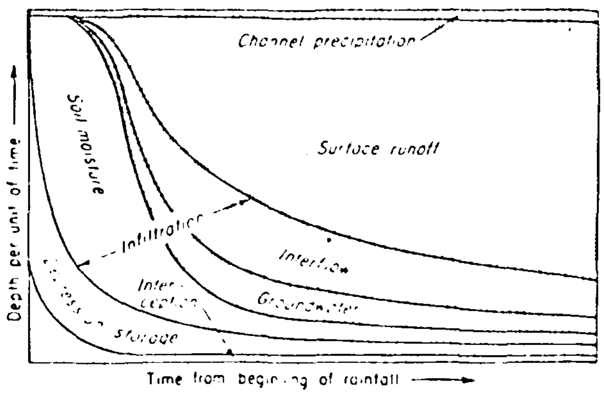
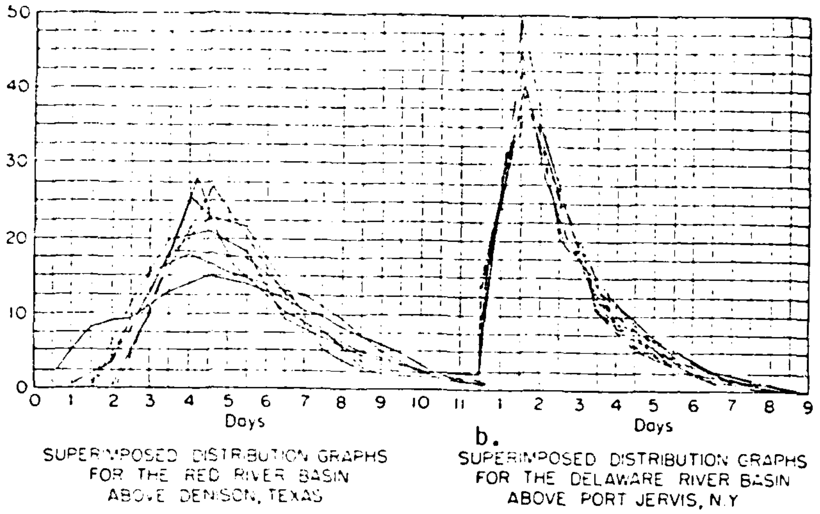


Figure A-2. Normalized distribution of storm runoff.

a. Red River Basin above Denison, Texas
b. Delaware River Basin above Port Jervis, New York



c. Susquehanna River at Tawanda, Pennsylvania

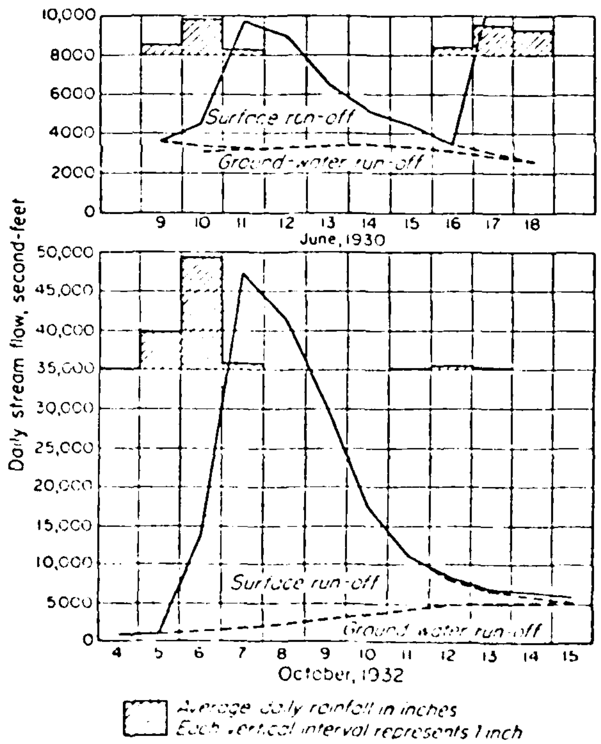


Figure A-3. Actual U. S. storm hydrographs.

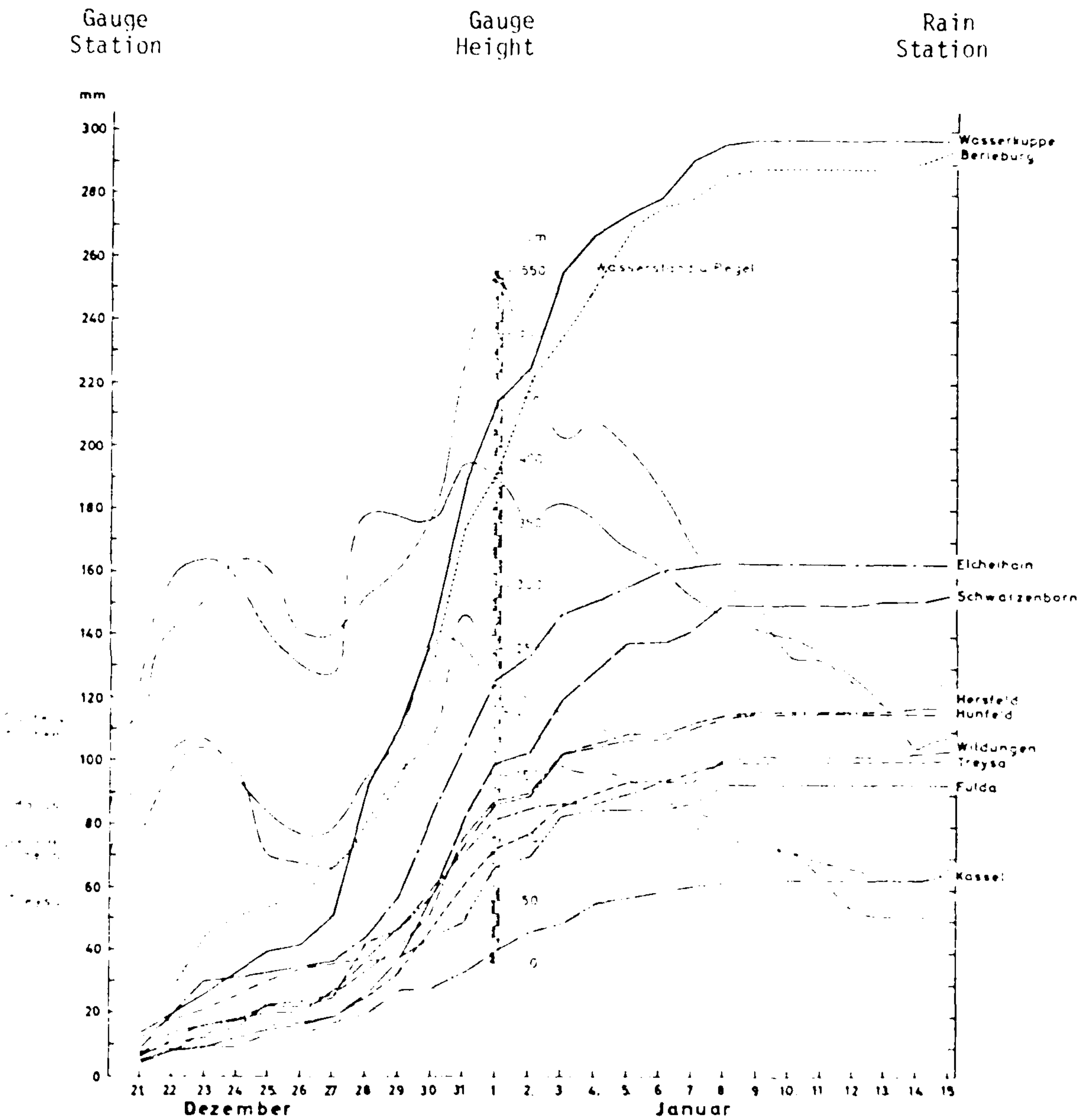


Figure A-4. River height response in Fulda basin (1926).

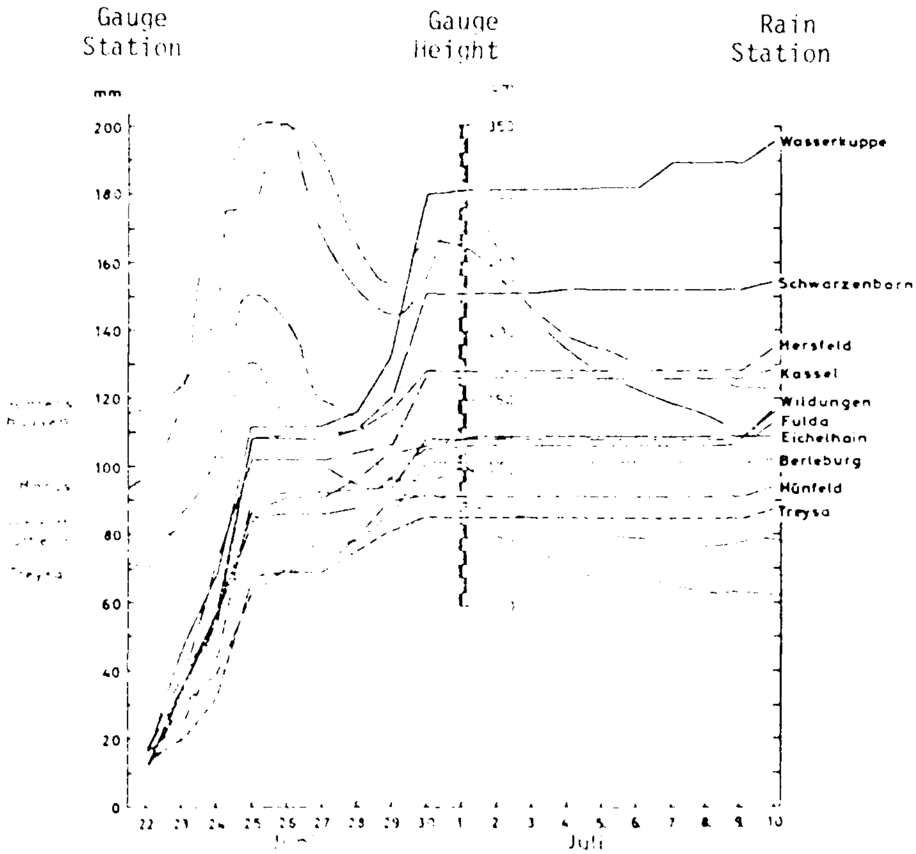


Figure A-5. River height response in Fulda basin (1933).

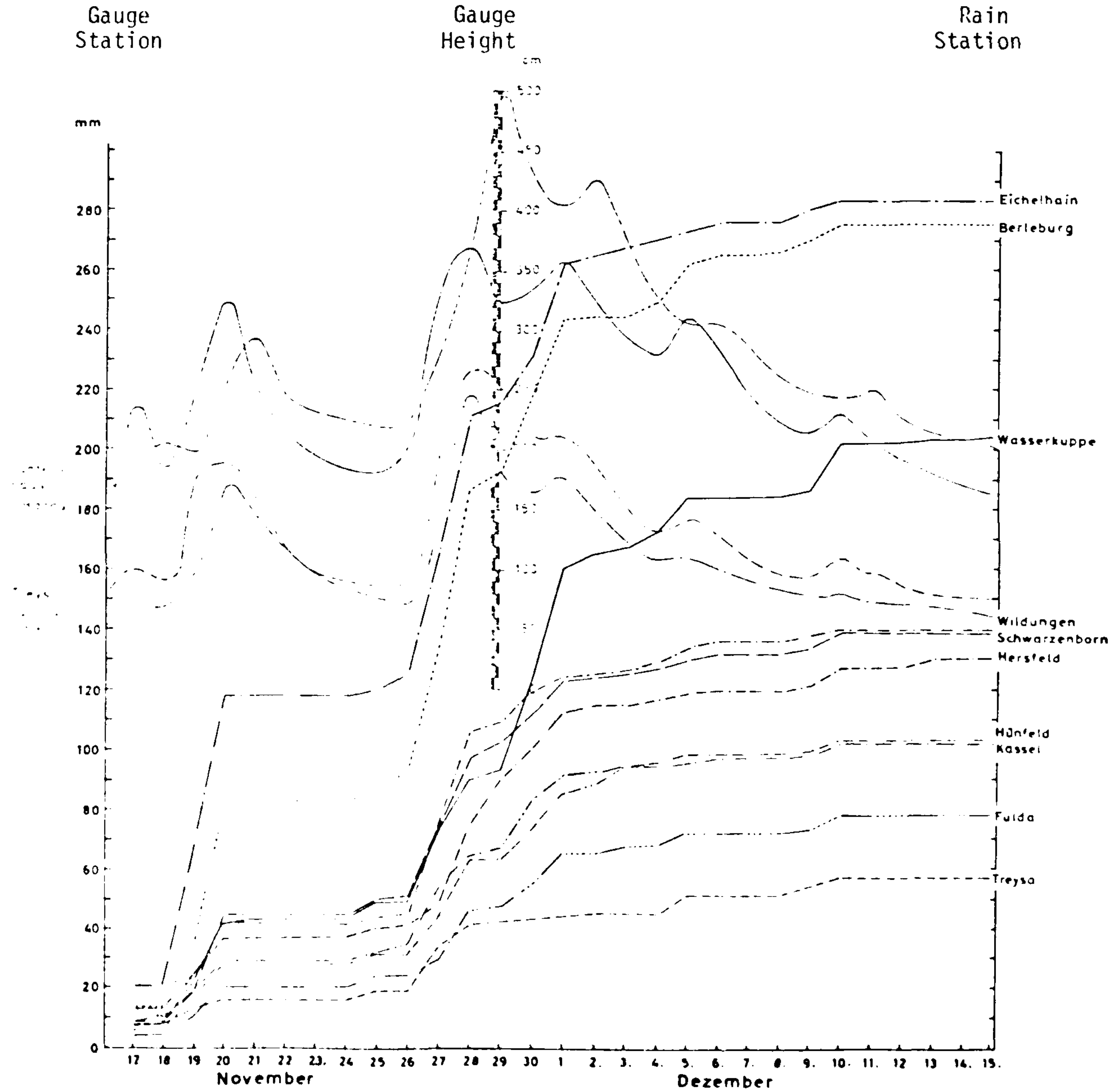


Figure A-6. River height response in Fulda basin (1939).

In the case where radioactive contamination occurs within the fourth day of excess precipitation (which produced surface runoff), the residual flow would produce some immediately contaminated stream flow. The area from which such flow would occur could be expected to be less than even the fractional amount of the runoff, as the entire surface area generally only contributes runoff while it is raining. Subsequent areas from which drainage is occurring are temporary ponds and lower areas of sheet flow. In consideration of the Fulda River basin topography and to provide a basis for the study, use of the following fractions of the surface area as contributors of surface runoff are recommended: day of precipitation, 100%; second day, 40%; third day, 8%; and fourth day, 2%.

A-4.3 Volume of Water on Watershed

An approximate volume of surface water on the WSP watershed is required for contamination and dilution assessment. The approximation developed below is based on prior estimates of normal and post-rain area of surface water, runoff of storm flow over time, ground water flow, and assumption of average stream velocities.

The volume of water on the watershed directly associated with rainfall depends on the volume of rain, the proportion of rain which becomes surface runoff, and the duration and shape of the storm hydrograph. An approximate flow distribution and time were assumed above. This is repeated in Table A-26 with the presumed area of watershed covered by surface water. It is assumed that the rain occurs on only the first day. Rain on the successive days or prior to complete recovery from a prior precipitation should be treated as discussed in conjunction with the antecedent precipitation index.

For the purpose of this study and with recognition that approximations are sought which would characterize the region and not

Table A-26. Storm runoff and area coverage factors.

Item	Day of Rain	2nd Day	3rd Day	4th Day
Distribution of Storm Runoff (day of passing the WSP)	0.38	0.44	0.11	0.07
Area Covered by Water (area contributing contamination to stream via surface water)	1.00	0.40	0.80	0.02

necessarily be exact for one specific watershed, it is assumed that the storm surface runoff and the runoff due to ground water may be treated independently and are additive. The principal considerations associated with this assumption relate to definitions of the types of runoff and stream flow.

There are several forms of surface runoff from a storm. Precipitation on flowing water has an immediate impact, however, the surface area is a very small percentage of the total. Some of the storm runoff flows directly through the stages of sheet flow into intermittent (ephemeral) streams (essentially carrying only surface runoff and therefore only existing while there is post-storm drainage) into perennial streams (which carry ground water and surface runoff and thus flow essentially all of the time). Other storm runoff is "interflow" which is surface runoff which is delayed due to ground surface conditions such as heavy vegetation, forest floor cover, or very localized ponding.

Interflow may also occur as lateral flow just below the surface which joins the stream flow in time to form part of the storm hydrograph (the runoff above that which would have occurred had the storm not taken place). The ground water flow is generally somewhat elevated after the storm discharge (4 days for the watersheds of this study), which can be attributed in part to slower interflow. The ground water recession is a much longer and continual process, as ground water runoff is dependent on periodic recharging the ground water level by precipitation. Another form of direct ground water influence on the storm hydrograph results from the temporary sharp rise in the water table adjacent streams carrying increased flow. The higher water level can raise the water table level in the banks sufficiently to reverse the hydraulic gradient to away from the stream, surcharging the adjacent ground and deferring the normal ground water. The impact of this temporary in-ground storm storage is to prolong the storm hydrograph and to raise the post-storm ground water flow. That flow of water that entered the channel as stream runoff and exited the ground adjacent to the stream banks during the

period of the storm hydrograph can be considered to be surface runoff for the purposes of this study.

The volume of storm water on the surface of a watershed may be determined from the definition of surface runoff (which is inexact), the volume of precipitation and the rate of runoff. The volume of surface runoff is the fraction of the excess precipitation which results in runoff. Table A-24 and Table A-25 provide average values by months of the year of the cummulative precipitation necessary for added surface runoff and the proportion of that excess rainfall which runs off. These provide the expression for surface runoff (SRO):

$$SRO = (SRO/P_e) \times (P_o + API - CPT)$$

where SRO/P_e is from Table A-25, CPT is from Table A-24 and the antecedent precipitation index (API) is determined by the time and amount of the preceding precipitation.

The volume of water on the watershed due to precipitation occurring on day one may be calculated from the value of SRO (in mm) derived using the expression above and the factors in Table A-26. The result is shown in Figure A-7. There is surface water on the watershed during and immediately following a storm which does not run off as surface runoff, but enters the ground or is evaporated (a very small proportion). This surface water is not included in Figure A-7. The amount of precipitation which is at the surface and then immediately or later enters the ground is essentially the total precipitation (P_o) less the surface runoff (SRO). This may be derived from the equation shown in the preceding paragraph.

The volume of ground water that is on the watershed surface at any time is dependent on the ground water flow (Table A-2), and shape, topogaphy, and size of the watershed. (summarized in Table A-1 for the representative WSP). This volume is akin to "Channel Storage", except that the term is associated with the excess volume of water in the streams due to a storm (part of the volume shown in Figure A-7).

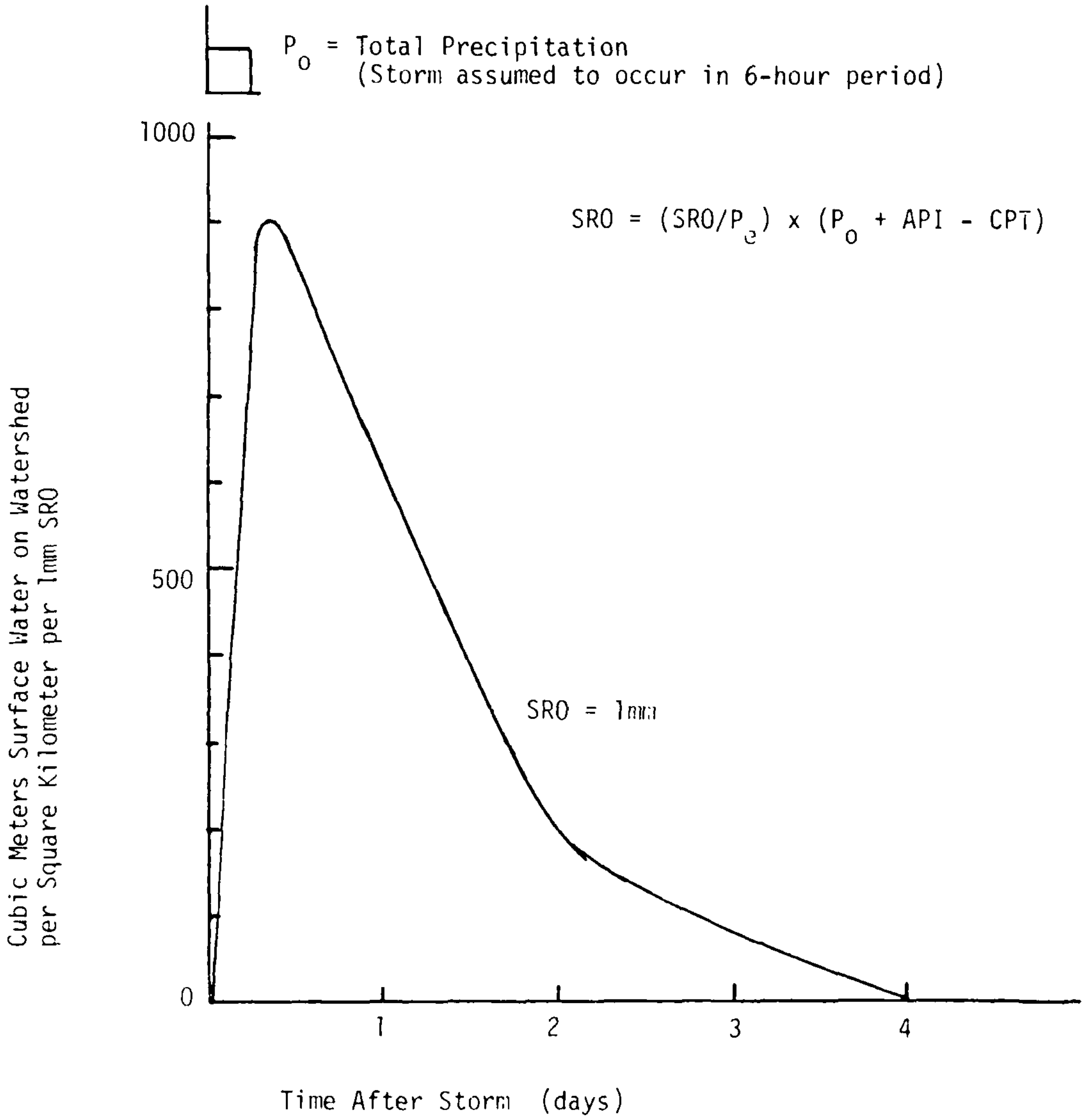


Figure A-7. Volume of storm runoff on watershed.

The volume in the streams when all flow is due to ground water (i.e., after the 4th day following a storm for the WSP watersheds being studied) can be equated to the ground water flow and average time that it takes emerging ground water to exit the watershed. The time of concentration (or lag time) discussed above and shown in Table A-1 is an indicator of the time that emerging ground water would take in transit to exit the watershed. (Note: it is assumed that the watershed boundaries apply to both surface and ground water runoff. This is not necessarily the case but these boundaries generally coincide in the Fulda River basin). The time of concentration may not be used directly as it relates to the time for precipitation falling at the extreme point on the watershed to contribute to the surface runoff at its exit. By definition, ground water would not enter the stream at that distance. Ground water becomes surface water at springs, which then become, essentially, the head of perennial flowing streams; or by seepage at the banks of a stream where a water table with hydraulic gradient toward the stream is intercepted by the stream banks. There can be some sheet flow associated with ground water emergence, however, in a cultivated area such sheet flow would generally have been intercepted by drainage ditches.

Values of time of concentration are partially determined by the difference in elevation and are based on storm flows, which are larger and at much increased velocities than when the streams are fed only by the ground water. Based on the average ground water flow (Table A-2), an average slope for the lower basin of about .03 (Table A-1), an assumed mean water depth of 1/4 foot taken is equal to the hydraulic radius, a value of n of 0.050 for a typical natural stream channel, and the Manning formula, an approximate average stream flow velocity at the watershed exit of 0.6 meters per second can be derived.[A-7] Use of this value and distance to the centroid of the watershed (Column (6) Table A-1) provides a basis for a rough approximation of

the average time for ground water to be on the surface of the watershed prior to exit (t_{ga}). The resulting expression for volume of ground water on the surface at any instant (V_g, in m^3) is as follows:

$$V_g(m^3) = A_u\ (\ell/sec/km^2) \times \text{Area}\ (km^2) \times t_{ga}\ (sec)\ /\ 1000$$

where A_u is from Table A-2 for the corresponding month

Area is from Table A-1, column (4)

t_{ga} = distance to center of area (km) (Table A-1, Col. (6)) x 1000/.6

The volume for ground water on the surface at any time may be added to the volume of storm surface runoff determined from Figure A-7 to provide an estimate of the total volume of surface water, flowing towards the exit, on a watershed at a given time.

SECTION A-5

CONCLUSIONS

The above discussion and tabulated data provide bases for determining: (1) the time following ground contamination that is likely to elapse before soluble components of the contaminant are apt to arrive at a water supply point, (2) the volume of water that may be expected to arrive; and (3) the sources of that water. Soluble material that enters the ground water would take much longer to arrive, and its arrival would be distributed over years. The estimated distribution of its arrival has not been estimated and application of such empirical and theoretical bases as exist for such calculations would be highly speculative.

In the absence of more detailed and coordinated German precipitation stream flow records, and with recognition of their intended application, the developed expressions appear appropriate. The times of concentration could generally be ignored due to their relative brevity, however, the estimates are provided (Table A-1) for use in any cases of surface runoff concurrent with or immediately following creation of neutron induced radioactivity, fallout, or rainout.

SECTION A-6

REFERENCES

A-1. "Wasserwirtschaftlicher Rahmenplan Fulda" (Fulda Water Resources Master Plan), Hessian Minister of Agriculture and Forestry, Wiesbaden, 1964.

A-2. Linsley, R. K., et al., "Hydrology for Engineers", 2nd Edition, McGraw-Hill, New York, 1975.

A-3. Private Communication, R. Farnsworth (Hydrology Laboratory, National Oceanic and Atmospheric Administration, Rockville, MD) to R. Sievers (SAI-McLean), October 1981.

A-4. Private Communication, C. White (New England River Forecast Center, U. S.Weather Service, Bloomfield, CT) to R. Sievers (SAI-McLean), October 1981.

A-5. Chow, V. T., "Handbook of Applied Hydrology", McGraw-Hill,New York, 1964.

A-6. Babbitt and Doland, "Water Supply Enginering", McGraw-Hill, New York, 1955.

A-7. Urquhart, L. C., "Civil Engineering Handbook", McGraw-Hill, New York, 1950.

APPENDIX B

WSWCM - Watershed Water Contamination Model

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION B-1

INTRODUCTION

This appendix presents a technical description of the computer code WSWCM (Watershed Water Contamination Model). WSWCM has been developed by Science Applications, Inc. (SAI) under contract to the Defense Nuclear Agency (DNA) for use on the project entitled "Nuclear Warfare Water Contamination Threat Assessment".

The purpose of the computer code WSWCM is to determine the radiological water contamination that would occur due to the radioactive fallout from a nuclear weapon detonation. The focus is on the water contamination threat to U. S. Army field forces that would arise in the event of nuclear warfare in Europe.

A review of the literature has shown that many water contamination models have been developed, and are being developed, to address specific situations such as the potential water contamination associated with chemical and nuclear waste storage facilities; land use changes like industrialization and urbanization; and the application of herbicides, pesticides, and fertilizers in agricultural areas.[B-1, B-2, B-3, B-4]* Typically, these models are very complex; require a considerable amount of detailed information on the characteristics of the contamination source, the relevant chemical and physical processes, and the water source; and are often "calibrated" so as to reproduce the results of actual field data. The application of such sophisticated models for this water contamination threat assessment is not appropriate nor necessary because of the scoping nature of the assessment and the lack of detailed input information.

*The number in the parentheses denotes a reference that is identified in Section B-5.

For the purposes of this assessment, a simple model which incorporated the major factors that affect water contamination and required a minimum of input data was deemed sufficient. Accordingly, it should be understood that WSWCM is a very simple water contamination model intended only for scoping-type calculations.

The technical approach used in WSWCM is discussed in Section B-2. A discussion of the computer programming for WSWCM, including input and output descriptions, is given in Section B-3. Section B-4 provides a sample problem that illustrates the use of WSWCM. Referenced material is identified in Section B-5.

SECTION B-2

TECHNICAL APPROACH

B-2.1 Overview

The Watershed Water Contamination Model (WSWCM) calculates the time-dependent activity concentration of fission product radionuclides dissolved in water that could result from the deposition of nuclear weapons' fallout on a watershed. WSWCM considers both the prompt water contamination that would result from the fallout material deposited directly in the water and the delayed water contamination that would result from the fallout material initially deposited on the land surface and subsequently transported to the water by precipitation runoff. All activity is assumed initially to be associated with solid particulate fallout. The activity may leave the watershed only by radioactive decay or by being dissolved in water which flows past the water supply point.

The principal characteristics of WSWCM are: (1) the watershed is modeled as a mixi_ tank, (2) radionuclide-specific distribution coefficients are used to address fallout solubility, and (3) the model treats radioactive decay including daughter in-growth. It is important to note that WSWCM addresses radioactive material in solution but does not incorporate any modeling of particulate or sediment transport.

The technical approach adopted for WSWCM is described in the following material. Section B-2.2 discusses the stream water contamination model that treats the prompt water contamination. The runoff water contamination model that treats the delayed water contamination is discussed in Section B-2.3. A discussion of the input data required for the models is given in Section B-2.4.

B-2.2 Stream Water Contamination Model

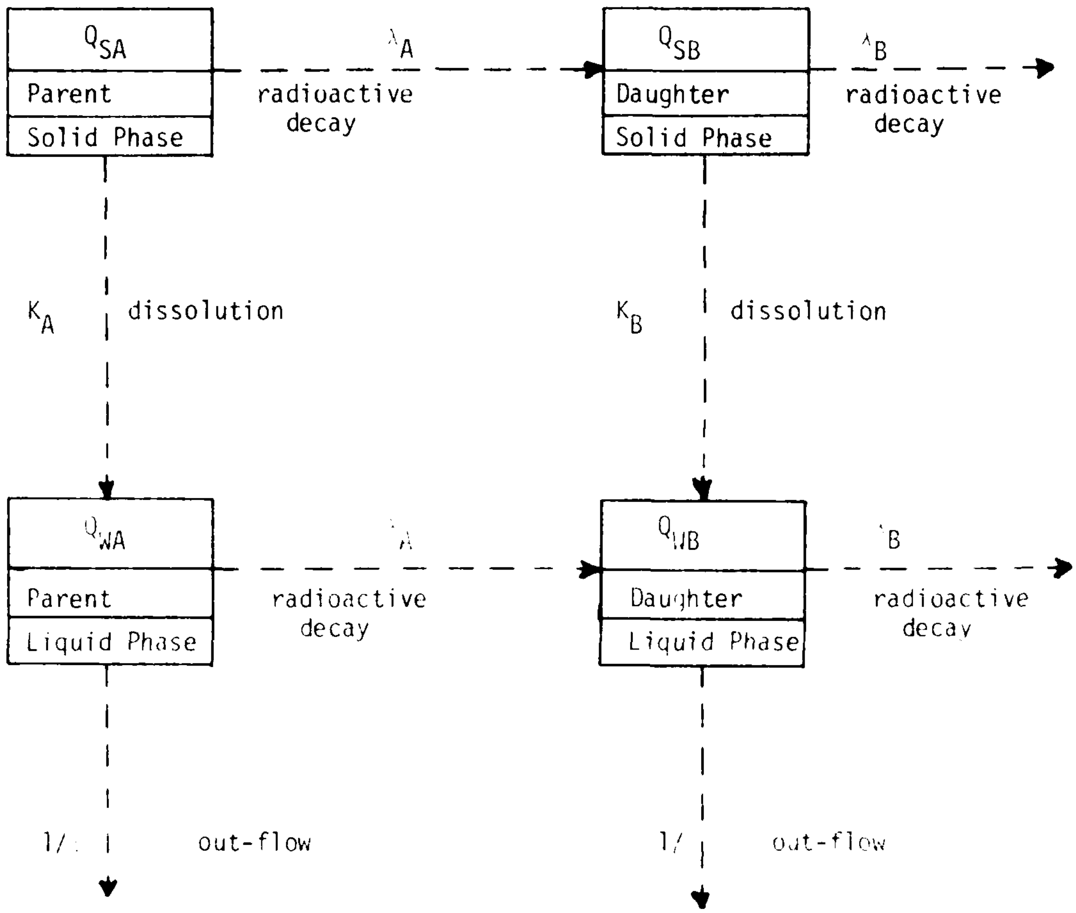
The stream water contamination model addresses the radiological contamination that results from the direct deposition of fallout material into the stream. The model determines the time-dependent concentrations of radionuclides in the stream water that passes the water supply point.

The stream water contamination model uses four separate compartments to represent the amount of parent and daughter radionuclides in solid and liquid phases. The mechanisms for transfer from one compartment to another compartment include: radioactive decay, dissolution from the solid phase to the liquid phase, and transport of liquid phase contaminants out of the system by water out-flow. The concentration of a radionuclide in the stream water is determined by dividing the activity present in the liquid phase by the volume of water in the stream.

The basic equations of the stream water contamination model are described in the following material. Section B-2.2.1 discusses the four-compartment model and the water concentration calculation. The modeling of the dissolution from the solid phase to the liquid phase is discussed in Section B-2.2.2. Section B-2.2.3 addresses the mixing tank model that is used to treat the liquid phase transport of contaminants out of the system.

B-2.2.1 Compartment Modeling and Concentration Calculation

The four-compartment model used to keep track of the amount of parent and daughter radionuclides in the solid and liquid phases is shown in Figure B-1. For each compartment, a differential equation can be written based on the rates at which material enters and leaves the compartment; the differential equation can then be solved to obtain the amount of material in the compartment as a function of time. These equations and their solutions are shown in Figure B-2.



Terminology

Q_{SA} - atoms of parent radionuclide in solid phase
Q_{SB} - atoms of daughter radionuclide in solid phase
Q_{WA} - atoms of parent radionuclide in liquid phase
Q_{WB} - atoms of daughter radionuclide in liquid phase
λ_A - radioactive decay constant for parent radionuclide (1/hr)
λ_B - radioactive decay constant for daughter radionuclide (1/hr)
K_A - dissolution rate from solid to liquid phase for parent radionuclide (1/hr)
K_B - dissolution rate from solid to liquid phase for daughter radionuclide (1/hr)
$1/\tau$ - rate of movement of material downstream (1/hr)

Figure B-1. Four-compartment model.

Compartment Q_{SA}

$$\frac{dQ_{SA}}{dt} = -(\lambda_A + K_A)Q_{SA}$$

$$\lambda_1 \equiv \lambda_A + K_A \quad \text{at } t = 0, \quad Q_{SA} = Q_{SA}(o)$$

$$Q_{SA}(t) = Q_{SA}(o) \cdot e^{-\lambda_1 t}$$

Compartment Q_{SB}

$$\frac{dQ_{SB}}{dt} = +\lambda_A Q_{SA} - (\lambda_B + K_B)Q_{SB}$$

$$\lambda_2 \equiv \lambda_B + K_B \quad \text{at } t = 0, \quad Q_{SB} = Q_{SB}(o)$$

$$Q_{SB}(t) = \frac{\lambda_A}{\lambda_2 - \lambda_1} \cdot Q_{SA}(o) \cdot [e^{-\lambda_1 t} - e^{-\lambda_2 t}] + Q_{SB}(o) \cdot e^{-\lambda_2 t}$$

Compartment Q_{WA}

$$\frac{dQ_{WA}}{dt} = +K_A Q_{SA} - (\lambda_A + 1/\tau)\, Q_{WA}$$

$$\lambda_3 \equiv \lambda_A + 1/\tau \quad \text{at } t = 0, \quad Q_{WA} = Q_{WA}(o)$$

$$Q_{WA}(t) = \frac{K_A}{\lambda_3 - \lambda_1} \cdot Q_{SA}(o) \cdot [e^{-\lambda_1 t} - e^{-\lambda_3 t}] + Q_{WA}(o) \quad e^{-\lambda_3 t}$$

Compartment Q_{WB}

$$\frac{dQ_{WB}}{dt} = +K_B Q_{SB} + \lambda_A Q_{WA} - (\lambda_B + 1/\tau)\, Q_{WB}$$

$$\lambda_4 \equiv \lambda_B + 1/\tau \quad \text{at } t = 0, \quad Q_{WB} = Q_{WB}(o)$$

$$Q_{WB}(t) = \frac{K_B \cdot \lambda_A}{\lambda_2 - \lambda_1} \cdot Q_{SA}(o) \cdot \left[\frac{e^{-\lambda_1 t}}{\lambda_4 - \lambda_1} - \frac{e^{-\lambda_2 t}}{\lambda_4 - \lambda_2}\right] + \frac{K_B \cdot Q_{SB}(o)}{\lambda_4 - \lambda_2} \cdot e^{-\lambda_2 t}$$

$$+ \frac{K_A \cdot \lambda_A}{\lambda_3 - \lambda_1} \cdot Q_{SA}(o) \cdot \left[\frac{e^{-\lambda_1 t}}{\lambda_4 - \lambda_1} - \frac{e^{-\lambda_3 t}}{\lambda_4 - \lambda_3}\right] + \frac{\lambda_A \cdot Q_{WA}(o)}{\lambda_4 - \lambda_3} \cdot e^{-\lambda_3 t}$$

$$+ \left[Q_{WB}(o) + \frac{K_B \cdot \lambda_A \cdot Q_{SA}(o)}{(\lambda_4 - \lambda_1) \cdot (\lambda_4 - \lambda_2)} - \frac{K_B \cdot Q_{SB}(o)}{\lambda_4 - \lambda_2} + \frac{K_A \cdot \lambda_A \cdot Q_{SA}(o)}{(\lambda_4 - \lambda_1) \cdot (\lambda_4 - \lambda_3)} \right.$$

$$\left. - \frac{\lambda_A \cdot Q_{WA}(o)}{\lambda_4 - \lambda_3}\right] \cdot e^{-\lambda_4 t} \quad .$$

Figure B-2. Compartment equations and solutions.

The model and equations given in Figures B-1 and B-2 are used to determine the amount of a radionuclide present in the liquid phase; for example, $Q_{wi}(t)$ for radionuclide i. The activity concentration of the radionuclide, $C_{wi}(t)$, is determined by its radioactive decay constant, λ_i, and the volume of water in the stream, V, by

$$C_{wi}(t) = \frac{\lambda_i \, Q_{wi}\,(t)}{V}$$

B-2.2.2 Dissolution of Radionuclides*

At equilibrium, the distribution of a radionuclide between the solid phase and the liquid phase is expressed by a radionuclide-specific distribution coefficient, Kd. By definition,

$$Kd = \frac{\text{amount of radionuclide sorbed on solid phase}}{\text{amount of radionuclide left in solution}},$$

so

$$Kd = \frac{Q_s^{eq}\ /m}{Q_w^{eq}\ /V}$$

where

Q_s^{eq} = amount of the radionuclide present in the solid phase at equilibrium,

Q_w^{eq} = Amount of the radionuclide present in the liquid phase at equilibrium,

m = mass of solid phase material, and

V = volume of liquid phase material.

*In this discussion, the subscript i, denoting a specific radionuclide, has been intentionally omitted to avoid unduly complicating the equations.

The dissolution of a radionuclide from the solid phase to the liquid phase is modeled as a first order reaction with a constant coefficient,

$$\frac{dQ_s}{dt} = -k\,Q_s$$

So

$$Q_s = Q_s(o)e^{-kt}$$

[illegible] that the radionuclide is initially present only in the solid [illegible],

$$[illegible]$$

where [illegible] amount of the radionuclide present in both [illegible]

$$[illegible]\,e^{-kt}$$

$$[illegible]\;Q_w^{eq}$$

$$[illegible]$$

$$[illegible]\,[1 + \frac{V}{mK_d}]$$

$$[illegible]\;Q^{eq}\,[1 + \frac{V}{mK_d}]\,e^{-kt}.$$

[illegible] model it is assumed that the equilibrium between the solid [illegible] phases is achieved within a time corresponding to the time [illegible] of the [illegible] tank model, [illegible]. So

$$Q_s^{eq} = Q_s^{eq}\,[1 + \frac{V}{mK_d}]\,e^{-kt}$$

thus

$$k = \frac{1}{\tau} \ln \left[1+\frac{V}{mKd}\right]$$

B-2.2.3 Mixing Tank Model

The portion of the stream that is up-stream from the water supply point is considered to be a mixing tank in which instantaneous and uniform mixing of the fallout material and the stream water occurs. A time characteristic for this mixing tank model is obtained by dividing the volume of water in the stream by the stream flow rate.

With a mixing tank model, the amount of a contaminant in the stream is given by

$$X(t) = X_0 e^{-t/\tau}$$

where

X_0 is the initial amount of the contaminant, and
τ is the time characteristic of the model.

B-2.3 Runoff Water Contamination Model

The runoff water contamination model addresses the radiological contamination that results from the fallout material that is initially deposited on the land surface and is subsequently transported to the water by precipitation runoff. The model determines the time-dependent concentrations of radionuclides in the runoff water and couples the watershed runoff with the stream water flow to give the contamination of the water that passes the water supply point.

The runoff water contamination model follows the activity of parent and daughter radionuclides during the time after initial surface deposition when they are subjected to successive rains. The radioactive material in the solid phase is affected by radioactive

decay and dissolution into the liquid phase. The radioactive material in the liquid phase is also affected by radioactive decay and transport off the land into the stream by precipitation runoff.

The basic equations of the runoff water contamination model are described in the following material. Section B-2.3.1 discusses the method used to determine the amount of parent and daughter radionuclides in each phase as time progresses. The runoff water flow model is addressed in Section B-2.3.2. The equations used to determine the stream water contamination that results from the contaminated runoff water are discussed in Section B-2.3.3.

B-2.3.1 Contamination Time Sequence Modeling

The time sequence modeling used for the runoff water contamination model assumes that the fallout material is deposited on the land surfae at time t_0 and rains subsequently occur at times t_1, t_2, ...t_n. Each rain causes a partioning of the radioactive material between the solid phase and the liquid phase. The material in the solid phase remains on the land surface and is subjected to further phase partioning by successive rains. The material in the liquid phase is transported off the land surface and into the stream by the precipitation runoff.

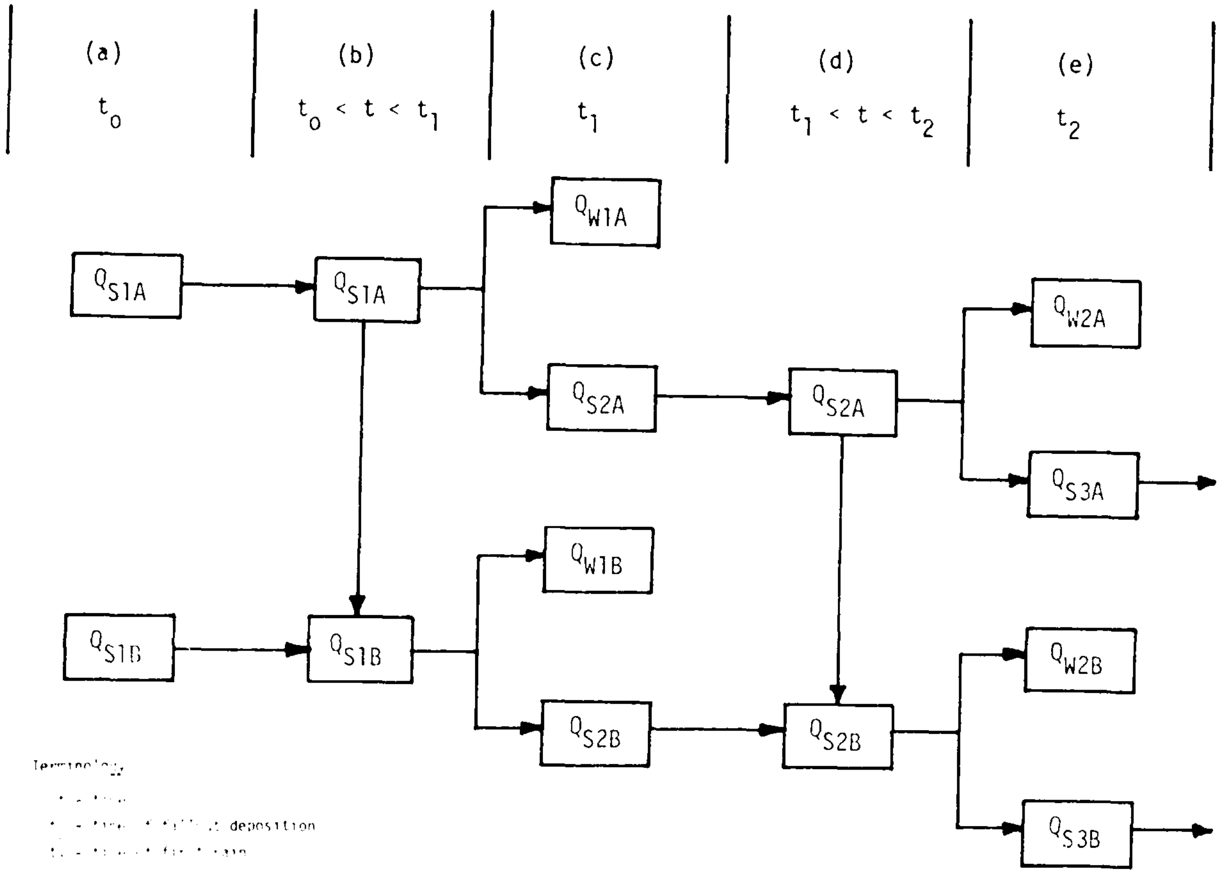
Figure B-3 shows the sequence of events for the radioactive material, both parent and daughter radionuclides, present in the solid phase. Each of these events is described below:

(a) $t = t_0$. The initial amounts of parent and daughter radionuclides present in the solid phase are given by Q^0_{S1A} and Q^0_{S1B}, respectively.

(b) $t_0 < t < t_1$. During the time period prior to the first rain, the process of radioactive decay affects the amount of the parent and daughter radionuclides present in the solid phase. So,

$$Q_{S1A}(t) = Q^0_{S1A}e^{-\lambda_A t} \quad \text{and}$$

$$Q_{S1B}(t) = Q^0_{S1A}\cdot\left(\frac{\lambda_A}{\lambda_B - \lambda_A}\right)\left[e^{-\lambda_A t} - e^{-\lambda_B t}\right] + Q^0_{S1B}e^{-\lambda_B t}.$$



Terminology

... deposition

Q_{S3B} - atoms of daughter radionuclide in solid phase prior to third rain

Figure B-3. Sequence of events for material in solid phase.

where λ_A and λ_B are the radioactive decay constants for the parent and daughter radionuclides, respectively.

<u>(c) t = t1.</u> the first rain occurs at time t_1. It is assumed that the radionuclides instantaneously reach an equilibrium distribution between the solid phase and the liquid phase.

As pointed out in Section B-2.2.2, the distribution coefficient Kd is given by the expression*

$$Kd = \frac{Q_S/m}{Q_W/V}$$

so

$$Q_W = Q_S \cdot \frac{V}{mKd} \quad ;$$

but the total amount of the radionuclide, Q_T, is

$$Q_T = Q_S + Q_W$$

so

$$Q_T = Q_S \cdot \left[1 + \frac{V}{mKd}\right]$$

or

$$Q_S = Q_T \cdot \left\{\left[1 + \frac{V}{mKd}\right]^{-1}\right\}$$

with, of course,

$$Q_W = Q_T \cdot 1 - \left\{\left[1 + \frac{V}{mKd}\right]^{-1}\right\}$$

This dissolution of a radionuclide from the solid phase to the liquid phase results in the following equations:

---

*Note that different values of m and V are used for the stream water contamination model and the runoff water contamination model.

$$Q_{S2A}(t_1) = Q_{S1A}(t_1) \cdot \left[1 + \frac{V_1}{mKd_A}\right]^{-1}$$

and

$$Q_{S2B}(t_1) = Q_{S1B}(t_1) \cdot \left[1 + \frac{V_1}{mKd_B}\right]^{-1}$$

where specific distribution coefficients are used for the parent and daughter radionuclides (Kd_A and Kd_B, respectively), and V_1 indicates the volume of potential runoff water associated with the first rain.

(d) $t_1 < t < t_2$. During the time period between the first and the second rain, the process of radioactive decay affects the amount of the parent and daughter radionuclides present in the solid phase. So,

$$Q_{S2A}(t) = Q_{S2A}(t_1) \cdot e^{-\lambda_A(t-t_1)}$$

and

$$Q_{S2B}(t) = Q_{S2A}(t_1) \cdot \left(\frac{\lambda_A}{\lambda_B - \lambda_A}\right)\left[e^{-\lambda_A(t-t_1)} - e^{-\lambda_B(t-t_1)}\right] + Q_{S2B}(t_1) \cdot e^{-\lambda_B(t-t_1)}$$

(e) $t = t_2$. The second rain occurs at time t_2. This rain causes another partitioning of the radioactive material into the solid and liquid phases.

So,

$$Q_{S3A}(t_2) = Q_{S2A}(t_2) \cdot \left[1 + \frac{V_2}{mKd_A}\right]^{-1}$$

and

$$Q_{S3B}(t_2) = Q_{S2B}(t_2) \cdot \left[1 + \frac{V_2}{mKd_B}\right]^{-1}$$

This modeling of decay and dissolution can be continued as long as the radioactive material present in the solid phase serves as a source for the radiological contamination of the water.

As was seen in Figure B-3, radioactive material enters the liquid phase at the time of each rain, (i.e., t_1, t_2, etc.). Each rain is treated as in individual event and the amount of radioactive material present in the liquid phase is affected only by radioactive decay.

For the first rain, the amount of radioactive material initially present in the liquid phase is given by

$$Q_{W1A}(t_1) = Q_{S1A}(t_1) \cdot \left\{1 - \left[1 + \frac{V_1}{mKd_A}\right]^{-1}\right\}$$

and

$$Q_{W1B}(t_1) = Q_{S1B}(t_1) \cdot \left\{1 - \left[1 + \frac{V_1}{mKd_B}\right]^{-1}\right\} .$$

At any subsequent time, the amount of parent and daughter radionuclides present in the liquid phase, as a result of the first rain, is given by

$$Q_{W1A}(t) = Q_{W1A}(t_1) \cdot e^{-\lambda_A(t-t_1)}$$

and

$$Q_{W1B}(t) = Q_{W1A}(t_1) \cdot \left(\frac{\lambda_A}{\lambda_B - \lambda_A}\right) \cdot \left[e^{-\lambda_A(t-t_1)} - e^{-\lambda_B(t-t_1)}\right] + Q_{W1B}(t_1) \cdot e^{-\lambda_B(t-t_1)} .$$

Similar equations can be written for the second rain; specifically,

$$Q_{W2A}(t_2) = Q_{S2A}(t_2) \cdot \left\{1 - \left[1 + \frac{V_2}{mKd_A}\right]^{-1}\right\} ,$$

$$Q_{W2B}(t_2) = Q_{S2B}(t_2) \cdot \left\{1 - \left[1 + \frac{V_2}{mKd_B}\right]^{-1}\right\}$$

$$Q_{W2A}(t) = Q_{W2A}(t_2) \cdot e^{-\lambda_A(t-t_2)} \quad \text{and}$$

$$Q_{W2B}(t) = Q_{W2A}(t_2) \cdot \left(\frac{\lambda_A}{\lambda_B - \lambda_A}\right) \cdot \left[e^{-\lambda_A(t-t_2)} - e^{-\lambda_B(t-t_2)}\right] + Q_{W2B}(t_2) \cdot e^{-\lambda_B(t-t_2)} .$$

B-2.3.2 Runoff Water Flow Model

Figure B-4 shows the time history of runoff water on the watershed. The figure is based on an engineering estimate of the hydrological characteristics of a typical watershed. The key features of the time history are: (1) the volume of water on the surface reaches a maximum at 8 hours, (2) the surface runoff is completed in 4 days, and (3) the integral of the time history curve is 1000 m^3/Km^2 per mm of SRO (surface runoff).

An approximation to the time history curve of Figure B-4 can be developed by considering a mathematical model for the volume of surface water, V(t), that has an input rate of $R_o e^{-\lambda t}$ and an output rate of kV.

Mathematically,

$$\frac{dV}{dt} = + R_o e^{-\lambda t} - kV$$

with $$V(o) = o$$

thus $$V(t) = R_o \cdot \frac{1}{k-\lambda} \cdot \left[e^{-\lambda t} - e^{-kt}\right].$$

The values of the parameters of the equation (i.e., R_o, k, and λ) can be determined by trial and error with the objective of matching the three key features of the time-history curve shown in Figure B-4. The parameter values of R_o = 313.7 m^3/hr per mm of SRO, k = 0.0348 1/hr, and λ = 0.3011 1/hr provide a suitable fit, as shown in Figure B-4.

Using this model approximation, the rate at which the runoff water flows off the watershed given by

$$F = kV$$

or

$$F(t) = R_o \cdot \frac{k}{k-\lambda} \cdot \left[e^{-\lambda t} - e^{-kt}\right]$$

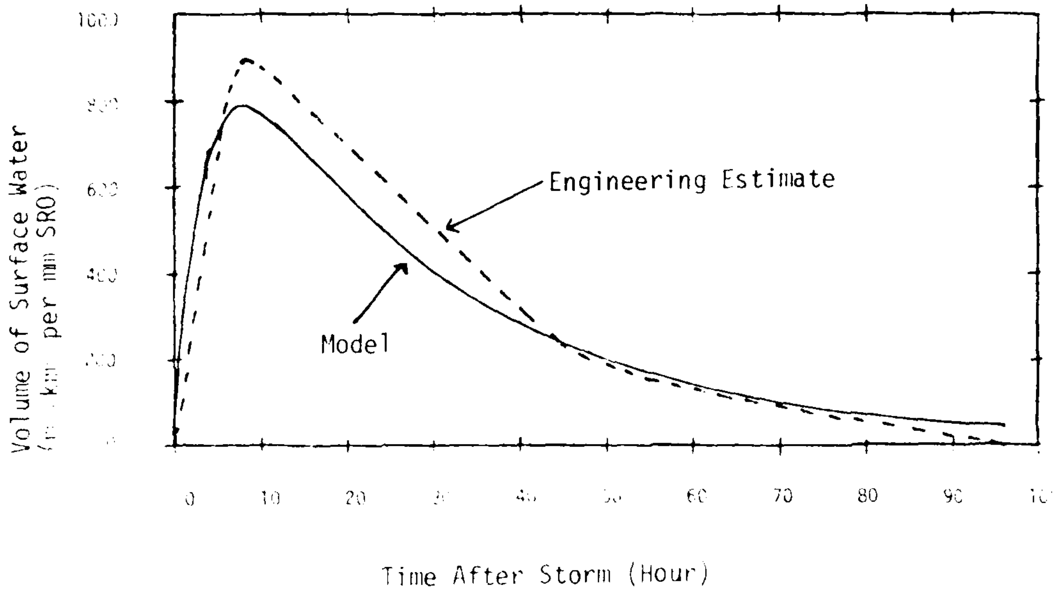


Figure B-4. Volume of storm runoff on watershed.

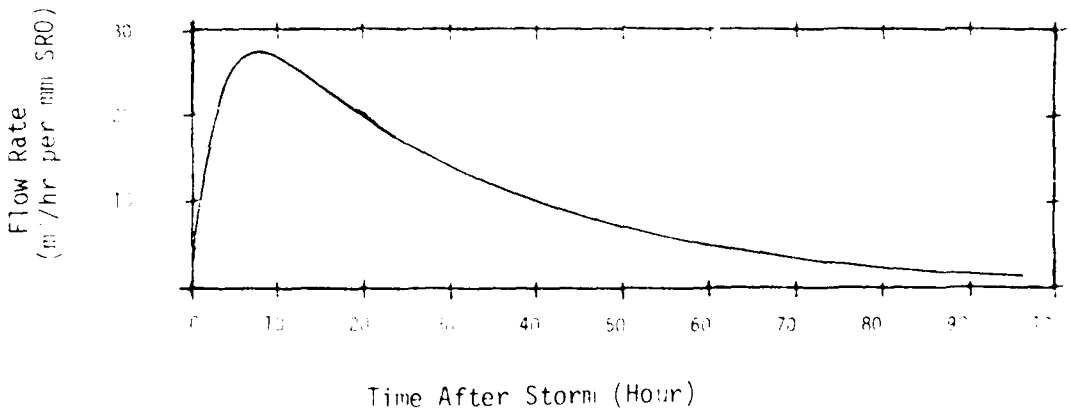


Figure B-5. Flow rate of runoff water.

where

$F(t)$ = flow rate of runoff water, m^3/hr per mm of SRO,

R_0 = 313.7 m^3/hr per mm of SRO (a fitted constant),

k = 0.0348 1/hr (a fitted constant), and

λ = 0.3011 1/hr (a fitted constant).

A plot of the runoff water flow rate as a function of time is shown in Figure B-5.

B-2.3.3 Water Contamination Calculation

The equations presented in Section B-2.3.1 determine the amount of parent and daughter radionuclides present in the liquid phase as a function of time for a specific rain. The activity concentration of the radionuclides in water is determined by the radionuclide radioactive decay constant and the volume of potential runoff water associated with the rain. For example, the i^{th} rain,

$$C_{wiA}(t) = \frac{\lambda_A \cdot Q_{wiA}(t)}{V_i}$$

and

$$C_{wiB}(t) = \frac{\lambda_B \cdot Q_{wiB}(t)}{V_i}$$

The material presented in Section B-2.3.2 described a runoff water flow model and presented an equation for the time-dependent flow rate for the i^{th} rain, $F_i\ (t-t_i)$.

When the contaminated runoff water enters the stream, it mixes with the normal stream flow, F, and the existing stream water contamination $C_{wA}(t)$ and $C_{wB}(t)$, as determined by the model described in Section B-2.2

The resulting water contamination is given by

$$C_A(t) = \frac{F \cdot C_{wA}(t) + \sum_{i=1}^{n} F_i(t-t_i) \cdot C_{wiA}(t)}{F + \sum_{i=1}^{n} F_i(t-t_i)}$$

and

$$C_B(t) = \frac{F \cdot C_{wB}(t) + \sum_{i=1}^{n} F_i(t-t_i) \cdot C_{wiB}(t)}{F + \sum_{i=1}^{n} F_i(t-t_i)}$$

where the $\sum_{i=1}^{n}$ indicates the inclusion of up to n rains.

B-2.4 Input Data for Models

The stream water contamination model and the runoff water contamination model require three basic types of input data or information: (1) fission product radionuclide data, (2) information on watershed and precipitation characteristics, and (3) data and information for solubility modeling. The following material discusses the approach used to provide the necessary data and information for each of the three categories.

B-2.4.1 Fission Product Radionuclides

The radioactive fallout from a nuclear weapon explosion contains several hundred fission product radionuclides. For a variety of reasons (e.g., relative yield, radioactive decay characteristics, water solubility, radiation dosimetry, etc.), not all of the fission product radionuclides are of significance to the water contamination threat analysis. Table B-1 lists those fission product radionuclides that have been identified as of importance to the threat analysis.*

In Table B-1, the radionuclides are given as parent-daughter pairs (e.g., Sr-90, and Y-90), where relevant. This is an important aspect of radioactive contamination modeling since there are cases

*This identification was based on an assessment of the relative importance of specific radionuclides present in unfractionated fission products in terms of ingestion dose commitments using data from Reference B-5.

Table B-1. Fission product radionuclides.

Parent Radionuclide	Normalized Ground Concentration* (Ci/km^2 for 1 R/hr at H+1)	Daughter Radionuclide	Normalized Ground Concentration* (Ci/km^2 for 1 R/hr at H+1)
		Sr-89	4.1
Sr-90	.027	Y-90	.0060
Sr-91	660.	Y-91	.21
Zr-95	4.8	Nb-95	.0030
Zr-97	410.	Nb-97	220.
Mo-99	100.	Tc-99m	0.0
Ru-103	4.2	Rh-103	0.0
Ru-105	270.	Rh-105	5.7
Ru-106	.079	Rh-106	0.0
Sb-127	2.2	Te-127	0.0
Te-129m	.070	Te-129	0.0
Te-131m	13.	I-131	15.
Te-132	71.	I-132	30.
		I-133	300.
		I-134	4400.
		I-135	990.
Ba-140	24.	La-140	.63
		Ce-141	.93
Ce-143	200.	Pr-143	.30
Ce-144	.94	Pr-144	0.0
		Cs-137	.28
Nd-147	11.	Pm-147	0.0

*The normalized ground concentrations were obtained using the SAI computer code FIIDOS described in Reference B-6. The calculated ratio of exposure rate to the surface contamination was 13.4 R/hr per Ci/m^2 at H+1 hour. This ratio is equivalent to 2400 R/hr per KT/mi^2, which compares quite well with the value of the K-factor reported in Reference B-7.

where the initial amount of a daughter radionuclide is small but large amounts are subsequently added by the radioactive decay of the parent radionuclide.

Table B-1 also shows the normalized ground concentration (Ci/Km^2 for 1 R/Hr at H+1 Hour) for each radionuclide. These concentrations are based on the calculated inventory of unfractionated, U-235 fission products present at one hour after the fission event occurs. The concentrations are referenced to a fallout deposition contour that has an above ground external radiation exposure rate of 1 R/Hr at H+1 hour.

B-2.4.2 Watershed and Precipitation Characteristics

The watershed and precipitation characteristics used in WSWCM pertain to possible field water supply points located in the preselected scenario area. This area, shown in Figure B-6, is bounded by Marburg, Giessen, Frankfurt am Main on the west, and the Fulda River valley on the east. The descriptive information on the watershed and precipitation characteristics for the scenario area is contained in Appendix A, "Water Source Information."

Tables B-2 and B-3 provide information on the watersheds that support specific potential water supply points sited in the scenario area. This information is used by WSWCM to determine the mixing tank time characteristic, τ, and the volume of water in the stream, V, for the stream water contamination model.

The time characteristic τ (hr), is determined by the distance from the center of the watershed to the water supply point, D (Km), and the estimated average stream flow velocity, S (m/s), by

$$\tau = \frac{D}{S} \cdot \frac{1}{3.6}$$

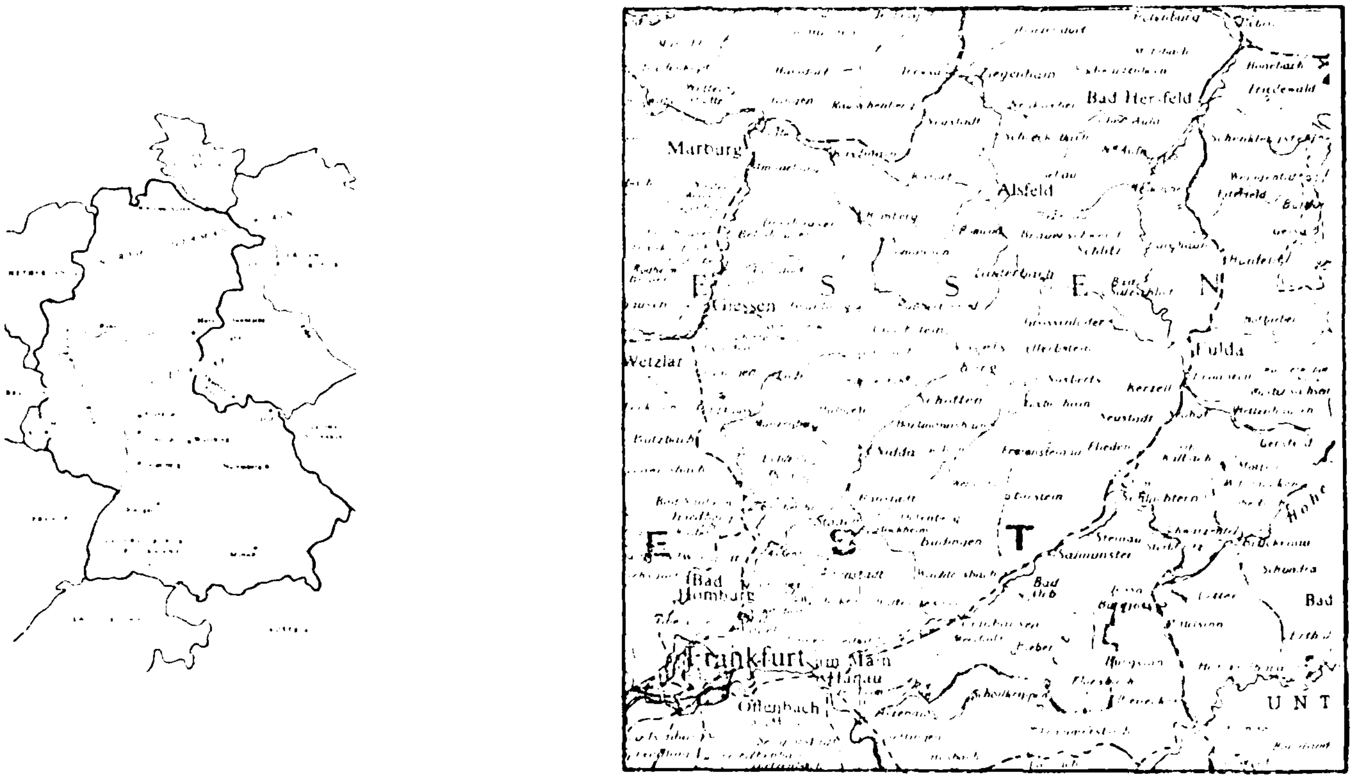


Figure B-6. Scenario area.

Table B-2. Selected data on water supply points.

Water Supply Point No.	Area (Km^2)	Distance from Center of Area to WSP (Km)
1	63.6	5.8
2	10.0	1.4
3	12.6	3.2
4	27.1	2.7
5	12.8	4.0
6	28.1	3.5
7	12.2	3.6
8	30.9	2.0
9	13.6	2.5
10	7.9	3.0
11	12.4	4.5
12	16.6	5.3
13	9.3	3.2
14	21.4	3.9
15	33.0	7.2
16	17.4	3.2
17	10.8	2.3
18	8.4	2.6
19	20.5	3.9
20	22.1	3.3
21	8.7	3.1
22	14.3	3.1
23	19.9	4.0
24	31.7	4.6
25	45.3	6.4
26	15.4	2.6
27	9.5	2.0
28	12.5	2.7
29	25.8	4.2
30	24.7	4.0
31	40.2	4.2

Table B-3. Ground water areal flow rate.

Month	Ground Water Runoff ($l/s/Km^2$)
January	3.7
February	5.0
March	4.9
April	5.0
May	3.0
June	2.3
July	1.9
August	1.9
September	1.9
October	2.2
November	3.1
December	3.4

where the factor 1/3.6 converts Km/m/s to hr. Values for D can be found in Table B-2 for each water supply point watershed. The average stream velocity at the watershed exit has been estimated to be 0.6 meters per second.

The volume of water in the stream V (ℓ), in the absence of precipitation runoff, is determined by the ground water areal flow rate, F (ℓ/s/Km^2), the area of the watershed, A (Km^2), and the watershed time characteristic, τ (hr), by

$$V = F \cdot A \cdot \tau \cdot (3600)$$

where the factor 3600 converts s to hr.

Tables B-4, B-5, and B-6 provide information on the precipitation characteristics of the scenario area. This information is used by WSWCM to determine the volume of surface runoff water caused by precipitation for the runoff water contamination model.

The volume of surface runoff water resulting from a given rain, V (ℓ), is determined by the area of the watershed, A (Km^2), and the linear amount of surface runoff water, SRO (mm), by

$$V = A \cdot SRO \cdot 10^6$$

where the factor 10^6 converts Km^2-mm to ℓ.

The linear amount of surface runoff water resulting from a given rain is determined by the amount of water deposited by the rain, the prior precipitation history of the watershed, and the hydrological characteristics of watershed. The equations used for calculating the linear amount of surface runoff are:

$$SRO = [SRO/P_e] \times P_e$$

with

$$P_e = P_o + API - CPI$$

Table B-4. Estimated proportion of excess rainfall which becomes surface runoff.

Month	Surface Runoff/Excess Rainfall
January	0.45
February	0.65
March	0.58
April	0.34
May	0.11
June	0.10
July	0.13
August	0.10
September	0.12
October	0.16
November	0.40
December	0.42

Table B-5. Daily precipitation data (mm) - Fulda (1975).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.4	0.2		t	t	t		6.5	2.7	0.1	1.7	
2	0.2	0.2	0.7	2.3	0.2	0.8			0.6	1.3	0.1	9.4
3				4.4	5.4	1.4			0.3	1.0		2.6
4			t	t	0.6	3.3	t		9.7	0.9		0.1
5	1.6				t				t	6.1		0.4
6	0.1		t	8.8	t							
7	9.2		6.3	1.7	4.1						t	0.2
8	0.2	t		4.8	10.7		t					t
9				t	t	3.9					1.1	
10			3.6	t		2.5				0.9	t	t
11		t	t	1.2	4.2		6.9	t	1.1		3.1	
12	0.7			2.3			0.5		9.6	6.4	7.1	
13	1.1	0.3	0.1	3.2					7.5	11.2		0.6
14		0.5	2.5	3.8			33.7		1.2	1.2	0.4	
15			1.0	11.2	t	4.3	t	0.1		0.6	1.5	
16			1.1	1.7	t			1.3			2.6	
17	2.3	t	0.2	t	2.0	24.3		4.6		4.1		
18	0.7	13.1	0.4	0.1	4.[illegible]	22.0	0.2	8.[illegible]	3.6	0.7	0.1	
19	0.8	4.[illegible]	5.4	3.0		3.3		0.2		0.3	7.5	
20	1.5		2.4	0.2		3.8	9.4	16.2			4.5	0.1
21	0.1						0.4	0.6	0.2		3.3	t
22	5.[illegible]					87.5		18.[illegible]	t	t	0.5	
23	1.[illegible]					0.1		0.2		t		
24	t		1.4			14.3	0.8	0.3				1.[illegible]
25	6.1		0.3		0.2		4.9		2.9	t		1.[illegible]
26			5.1						15.[illegible]	t	t	
27	3.9		7.5						0.6	0.1	1.[illegible]	
28	6.4		1.0						1.3		3.[illegible]	t
29	1.2				0.[illegible]	0.7			t		8.[illegible]	t
30	[illegible]		[illegible]		2.[illegible]	0.[illegible]		0.1	5.[illegible]	t	1.[illegible]	t
31	[illegible]							24.[illegible]				1.[illegible]

Table B-6. Cummulative precipitation necessary for added surface runoff.

Month	Threshold (mm)
January	8
February	4
March	5
April	9
May	12
June	12
July	13
August	13
September	12
October	12
November	10
December	9

and

$$API = \sum_n P_{o-n} \times (0.9)^n$$

where

SRO = surface runoff (mm)

$[SRO/P_e]$ = surface runoff-excess precipitation ratio, as given in Table B-4.

P_e = excess precipitation (mm)

P_o = 24-hour precipitation (mm); given in Table B-5

API = antecedent precipitation index (mm)

CPT = cumulative precipitation threshold (mm), given in Table B-6

P_{o-n} = 24-hour precipitation n days before the day of P_o (but if Po-n > CPT use Po-n = CPT, to avoid double counting of prior precipitation that resulted in surface runoff), as given in Table B-5.

B-2.4.3 Solubility Modeling

Very little information is available on the solubility of specific radionuclides present in nuclear weapons fallout. Information is also lacking on the rate at which the fallout dissolves and the radionuclides enter the liquid phase. Most of the statements found in the available literature regarding fallout solubility refer to fallout as basically insoluble but cite some radionuclides present in the fallout as soluble.

To handle solubility modeling in WSWCM use is made of radionuclide-specific distribution coefficients. Information on these distribution coefficients is found in those portions of the nuclear power literature dealing with environmental contamination of water bodies by routine releases from nuclear power plants and with the impacts of potential releases of radioactive material from long-term nuclear waste storage facilities.[B-8, B-9, B-10] The use of these distribution coefficients for fallout solubility modeling provides a reasonable approach in the absence of adequate data on actual fallout.

A distribution coefficient is defined as:

$$\frac{\text{amount of radionuclide sorbed on solid phase}}{\text{amount of radionuclide left in solution}}$$

Since the solid phase activity is usually expressed in units of Ci/g and the liquid phase activity in units of Ci/ml, Kd typically has units of ml/g. Table B-7 shows selected values of distribution coefficients for those elements whose radioisotopes are considered in WSWCM. For a specific element, the value of Kd is dependent upon the chemical state of the element, the type of solid matrix in which it exists, the physical characteristics of the solid and liquid phases, and the nature of the dissolution process; however, the actual relationship of the value of Kd to these is generally not known. Values of Kd are normally determined by laboratory or field experiments and, as shown in Table B-7, these values exhibit a wide range.

It is important to note that the distribution coefficients refer to the phase distribution of the radionuclide at equilibrium. In WSWCM, assumptions made about reaching equilibrium conditions are, in effect, assumptions regarding the rate at which the radionuclides dissolve. While these assumptions do not appear unreasonable, it is not really possible to validate them because of the absence of actual fallout data.

To use distribution coefficients in WSWCM it is necessary to specify the amount of solid phase material with which the radionuclide is associated. It has been assumed that this solid mass is the amount of soil, or fallout material, represented by a uniform deposition over the watershed area of material with a thickness of 100 microns and a density of 1.4 g/cc. These assumptions give the solid phase material a uniform areal density of 1.5×10^5 Kg/Km^2. This density is multiplied by the area of concern to determine the mass of solid phase material. For the stream water contamination model, the area is 1% of the watershed area; for the runoff water contamination model the area is 99% of the watershed area.

Table B-7. Selected distribution coefficients*.

Element	Kd (ml/g)
Ba	500
Ce	10,000
Cs	1,000
I	10
La	500
Mo	25
Nb	10,000
Nd	10,000
Pm	10,000
Pr	10,000
Rh	5,000
Ru	5,000
Sb	100
Sr	1,000
Tc	1
Te	100
Y	1,000
Zr	1,000

*These values were selected from References B-8 and B-9. Reported Kd values exhibit a wide range; for example the value for Zr ranges from 1000 to 10000 and the value for Sr ranges from 8 to 4000.

SECTION B-3

COMPUTER PROGRAM

B-3.1 Introduction

The computer program WSWCM is written in FORTRAN-IV for operation on the PDP-11 mini-computer at SAI-Schaumburg. WSWCM requires 16K memory storage. A typical WSWCM problem has a running time of 5 minutes. User problem input is provided from a keyboard terminal. Code output is directed to a printer and a disk file for subsequent data plotting.

WSWCM consists of a main program with seven subroutines. Stored data arrays in the code contain problem-independent data. Problem-dependent data is input by the user. Program output is printed and processed for input to a separate data plotting package. Figure B-7 illustrates the basic organization of WSWCM.

The following sections provide a more detailed description of WSWCM. The user input is discussed in Section B-3.2. Section B-3.3 describes the main program, subroutines, and stored data arrays. The program output is discussed in Section B-3.4. A Fortran listing of WSWCM is provided in Section B-3.5.

B-3.2 User Input

The user-supplied, problem-dependent input to the computer program WSWCM consists of three types of data: Basic problem data, precipitation data and radionuclide data. Table B-8 indicates the input data required.

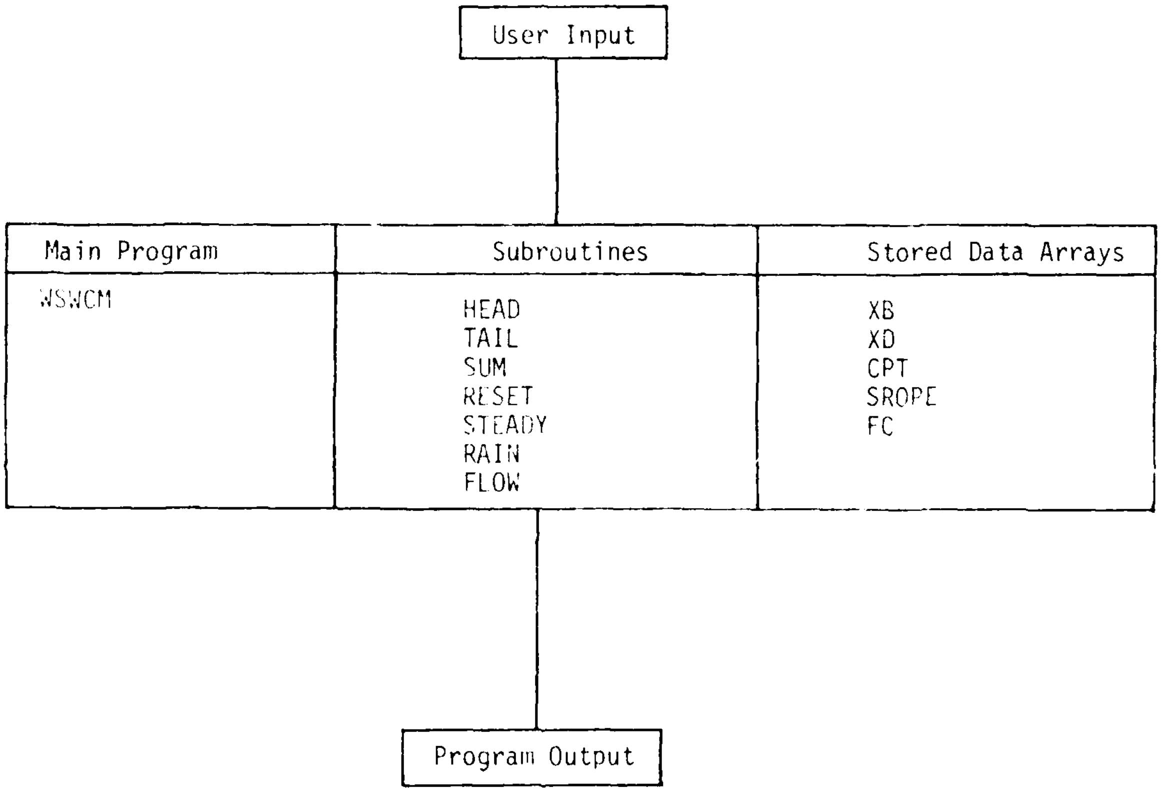


Figure B-7. Basic organization of WSWCM.

Table B-8. User input data required by WSWCM.

- - - - - - - - - Basic Problem Data - - - - - - - - -

1. Fallout Exposure Rate of Watershed
2. Problem Simulation Time
3. Identification Number of Water Supply Point
4. Month in which Problem Starts
5. Number of Rains during Problem Simulation Time
6. Number of Parent-Daughter Radionuclide Pairs

- - - - - - - - Precipitation Data - - - - - - - -

7. Time at which i^{th} Rain Occurs
8. Amount of Precipitation in i^{th} Rain
9. Antecedent Precipitation Index for i^{th} Rain
10. Month in which i^{th} Rain Occurs

- - - - - - - - Radionuclide Data - - - - - - - -

11. Identification Name of j^{th} Parent Radionuclide
12. Radioactive Half-Life of j^{th} Parent Radionuclide
13. Distribution Coefficient of j^{th} Parent Radionuclide
14. Normalized Ground Concentration of j^{th} Parent Radionuclide
15. Identification Name of j^{th} Daughter Radionuclide
16. Radioactive Half-Life of j^{th} Daughter Radionuclide
17. Distribution Coefficient of j^{th} Daughter Radionuclide
18. Normalized Ground Concentration of j^{th} Daughter Radionuclide

B-3.2.1 Basic Problem Data

The basic problem data is given on a single card image containing 6 data entries. These data entries correspond to the first six items listed in Table B-8.

(1) Fallout Exposure Rate of Watershed

Name: R

Format: E10.3

Remarks: The fallout exposure rate of the watershed is the normalized external exposure of the fallout expressed as R per Hr at H+1 Hour. This rate is assumed to be uniform over the watershed area.

(2) Problem Simulation Time

Name: LTMAX

Format: I5

Remarks: In the model, time starts at 0 and continues to LTMAX. LTMAX is expressed in hours.

(3) Identification Number of Water Supply Point

Name: NWSP

Format: I2

Remarks: The model contains data (see Section B-3.3 regarding stored data arrays) for 31 specific water supply points/watersheds.

(4) Month in which Problem Starts

Name: MOS

Format: I2

Remarks: The months of the year are numbered from 1 (January) to 12 (December).

(5) Number of Rains during Problem Simulation Time

Name: N

Format: I2

Remarks: None

(6) Number of Parent-Daughter Radionuclide Pairs

Name: NNUCS

Format: I2

Remarks: None

B-3.2.2 Precipitation Data

The precipitation data consists of 4 data entries (Items 7 through 10 of Table B-8) for each rain; the data for each rain is given on a single card image. The user must input N precipitation data card images (see Section B-3.2.1, Item 5).

(7) Time at Which i^{th} Rain Occurs

Name: LT1(I)

Format: I5

Remarks: LT1(I) is expressed in hours.

(8) Amount of Precipitation in i^{th} Rain

Name: XPO

Format: E10.3

Remarks: XPO is expressed in mm.

(9) Antecedent Precipitation Index for i^{th} Rain

Name: API

Format: E10.3

Remarks: API is expressed in mm.

(10) Month in which i^{th} Rain Occurs

Name: MOR

Format: I2

Remarks: The months of the year are numbered from 1 (January) to 12 (December).

B-3.2.3 Radionuclide Data

The radionuclide data is provided for parent-daughter radionuclide pairs on two card images; the first card image is for the parent radionuclide, the second card image is for the daughter radionuclide. Each card image contains 4 data entries; these entries correspond to items 11 through 14, or items 15 through 18, of Table B-8. The user must input NNUCS pairs of radionuclide data card images (see Section B-3.2.1, Item 6). If a radionuclide is not a member of a parent-daughter pair, the user enters null data for the parent and inputs the specific radionuclide data for the daughter radionuclide.

(11) Identification Names of j^{th} Parent Radionuclide

Name: NAMEA

Format: A4

Remarks: If the radionuclide pair doesn't have a enter NONE.

(12) Radioactive Half-Life of j^{th} Parent Radionuclide

Name: THALFA

Format: E10.3

Remarks: THALFA is expressed in hours. If the radionuclide pair doesn't have a parent enter 1.000E+00.

(13) Distribution Coefficient of j^{th} Parent Radionuclide

Name: XKDA

Format: E10.3

Remarks: XKDA is expressed in units of [illegible]/Kg. If the radionuclide pair doesn't have a parent enter 1.000E+00.

(14) Normalized Ground Concentration of j^{th} Parent Radionuclide

Name: GA

Format: E10.3

Remarks: GA is expressed in units of Ci per R/Hr at H+1 hour. If the radionuclide pair doesn't have a parent enter 0.000E+00.

(15) Identification Name of j^{th} Daughter Radionuclide

Name: NAMEB

Format: A4

Remarks: None

(16) Radioactive Half-Life of j^{th} Daughter Radionuclide

Name: THALFB

Format: E10.3

Remarks: THALFB is expressed in hours.

(17) Distribution Coefficient of j^{th} Daughter Radionuclide

Name: XKDB

Format: E10.3

Remarks: XKDB is expressed in units of [illegible]/Kg.

(18) Normalized Ground Concentration of j^{th} Daughter RADIONUCLIDE

Name: GB

Format: E10.3

Remarks: GB is expressed in units of Ci per R/Hr at H+1 hour.

B-3.3 Computer Program

The computer program WSWCM consists of a main program and seven subroutines. WSWCM also has stored data arrays that contain problem-independent data.

B-3.3.1 Main Program

The main program controls the operation of the model and performs some of the problem calculations and problem input/output operations. The basic flow of the main program is illustrated in Figure B-8.

As seen in Figure B-8, the main program initially assembles the basic problem data and precipitation data provided as user input, and some of the watershed and precipitation data provided by the stored data array; the data are used to calculate some of the watershed and precipitation parameters. The main program then begins to calculate water contamination values by processing each parent-daughter radionuclide pair in succession. For each parent-daughter pair, the main program reads the user-provided radionuclide data, calculates the initial water contamination and delayed water contamination, and outputs results. The water contamination calculations are performed using a time step of one hour for the first 24 hours of the problem and a time step of 3 hours for the remainder of the problem simulation time. The calculated results include the radionuclide concentration and the time integral of the radionuclide concentration, for both the parent and the daughter radionuclide, and a composite radionuclide concentration which aggregates all of the radionuclides.

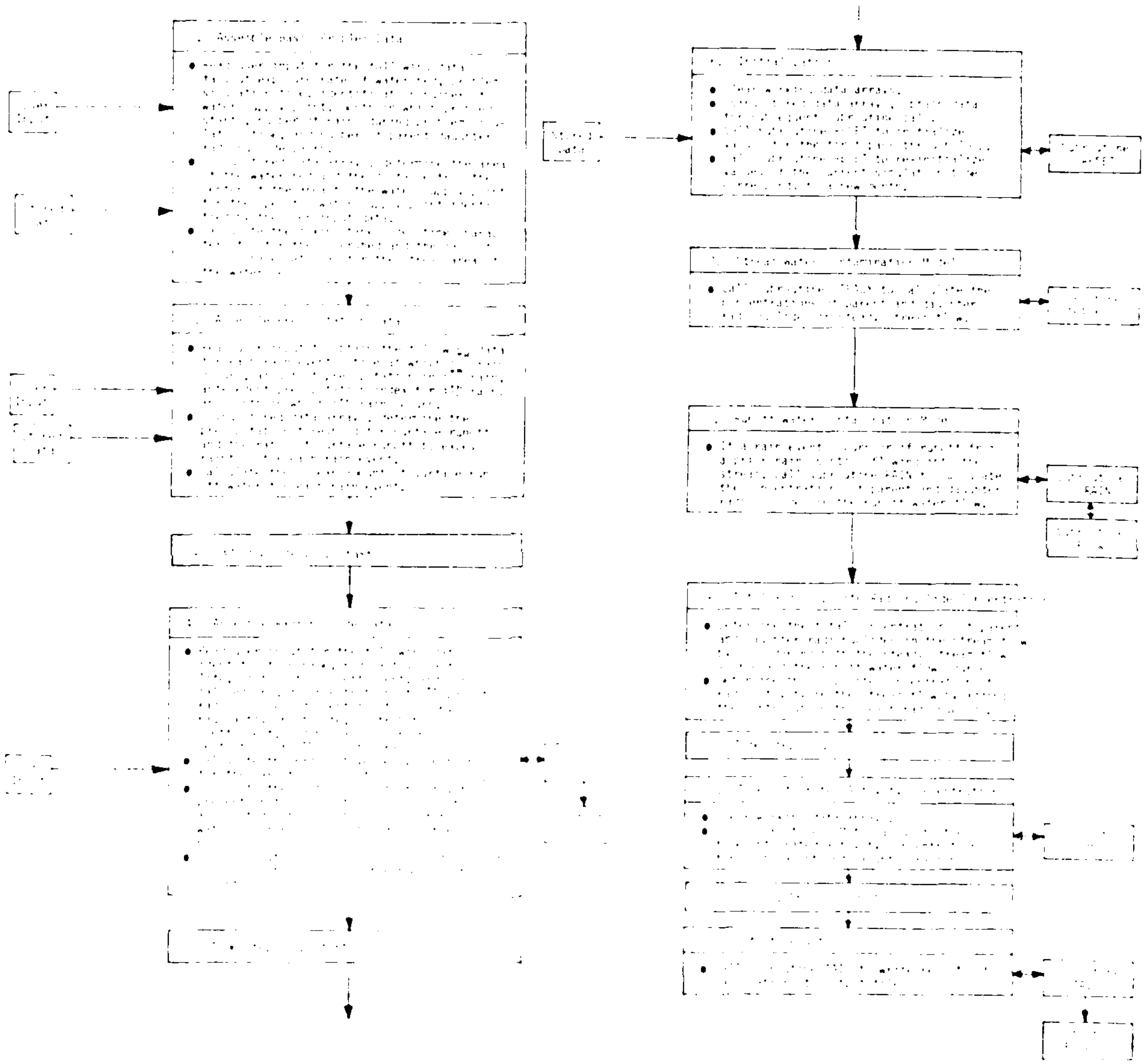


Figure B-8. Flow diagram for WSWCM.

Each parent-daughter radionuclide pair is processed through the model for the problem simulation time. After all radionuclide pairs have been processed, the problem is completed and the computer program terminates.

B-3.3.2 Subroutines

The main program flow diagram presented in Figure B-8 showed the calls made to the subroutines in WSWCM. Table B-9 lists the seven subroutines and identifies their purposes.

B-3.3.3 Stored Data Arrays

WSWCM has five stored data arrays that contain problem-independent data. Table B-10 lists the arrays and identifies the data contained in them.

B-3.4 Program Output

The output provided by the computer program WSWCM includes:

- o the radionuclide concentrations in water as a function of time for each parent-daughter radionuclide pair,
- o the radionuclide concentration in water as a function of time for all radionuclides present, and
- o the time-integrated radionuclide concentrations in water as a function of time for each radionuclide.

This output is directed to a disk file (Unit-2) to provide results for subsequent processing to a graphical form.*

---

*The output could also be directed to a printer (Unit-3) to provide results in a tabular form. FORTRAN Write statements for this purpose are contained in the WSWCM program, but have been Commented out since they are not needed if the disk file is used.

Table B-9. WSWCM subroutines.

HEAD	- This subroutine sets up the headings and labels on the data plots
RESET	- This subroutine initializes data values at the start of the program and at the beginning of each new month.
STEADY	- This subroutine calculates the radionuclide concentrations in the steady flowing stream in the absence of precipitation runoff
RAIN	- This subroutine calculates the radionuclide concentrations in the runoff water.
FLOW	- This subroutine calculates the time-dependent flow rate of the runoff water into the stream
SUM	- This subroutine performs trapezoidal integration of the time-dependent radionuclide concentrations to determine the integrated concentration
TAIL	- This subroutine writes the data arrays into the data plot file

Table B-10. WSWCM stored data arrays.

XB(31) - This array contains the area of each watershed, see Table 2-2

XD(31) - This array contains the distance from the center of the watershed area to the water supply point, see Table 2-2.

CPT(12) - This array contains the monthly data on the precipitation threshold for surface runoff, see Table 2-6

SROPE(12)- This array contains the monthly data on the ratio of the surface runoff to the excess rainfall, see Table 2-4

FC(12) - This array contains the monthly data on the ground water areal flow rate, see Table 2-3

The processing of the disk file to produce data plots is performed using a generalized plotting program written for the Versaplot-07 System [B-11] A FORTRAN listing of this program is provided in Section B-3.5. It should be noted that the program is not part of the WSWCM program and was not developed as part of this work.

B-3.5 Computer Program Listings

A FORTRAN listing of WSWCM is provided in Figure B-9. A FORTRAN listing of the figure plotting program used with WSWCM is provided in Figure B-10.

```
      PROGRAM WSP
C
C        A PROGRAM TO ESTIMATE ACTIVITY CONCENTRATIONS IN A STREAM
C        FOLLOWING A CONTAMINATING FALLOUT EVENT.  CONTAMINATION
C        DUE TO RUNOFF FOLLOWING RAINS IS INCLUDED.
C
C
C...THIS PROGRAM CREATED FEBRUARY, 1982 BY JIM A. ROBERTS AT SCIENCE
C...APPLICATIONS INC., SCHAUMBURG, ILLINOIS.  ITS INTENDED USE IS FOR
C...SCALING CALCULATIONS CONCERNING SMALL WATERSHEDS IN EUROPE.
C...HYDROLOGY DATA SPECIFIC TO THOSE WATERSHEDS ARE INCORPORATED IN
C...THE MODEL UPON WHICH THIS PROGRAM IS BASED.  USE OF THIS PROGRAM
C...FOR OTHER CALCULATIONS IS DISCOURAGED.
C
C
C...FC IS THE MONTHLY AVERAGE GROUNDWATER FLOW APPEARING ON THE
C   SURFACE OF THE WATERSHED (L/S*KM**2).
C...SROPE IS THE FRACTION OF EXCESS PRECIPITATION WHICH RUNS OFF
C   ON THE SURFACE, AVERAGED BY MONTH.
C...CPT IS THE MONTHLY AVERAGE PRECIPITATION THRESHOLD WHICH
C   MUST BE EXCEEDED BEFORE SURFACE RUNOFF BEGINS (MM).
C...H2O.DAT IS THE DATA INPUT FILE.
C...WATER.DAT IS AN OUTPUT FILE FOR INTEGRATED ACTIVITY CONCENTRATIONS.
C...PL.DAT IS AN OUTPUT FILE FOR PLOTTING ACTIVITY CONCENTRATIONS
C   VS. TIME USING PLOT PROGRAM BY EGBERT.
C...R IS R/HR AT 1M ABOVE GROUND AT H+1 HR.
C   H+1 HR IS THE START TIME FOR THIS PROGRAM.
C...B IS AREA OF THE WATERSHED (KM**2).
C...D IS THE DISTANCE TO THE CENTER OF THE WATERSHED (KM).
C...TAU IS THE AVERAGE RESIDENCE TIME (HR) FOR GROUNDWATER TO FLOW ON
C   SURFACE OF STREAM BEFORE IT PASSES THE WATER SUPPLY POINT (WSP).
C...BB IS THE AREA OF THE STREAM SURFACE (KM**2).
C...X4 IS THE MASS (KG) OF 100 MICRON SEDIMENTS WITH DENSITY
C   1.4 G/CM**3 IN THE STREAM BED.
C...LTMAX IS THE NUMBER OF HOURS FROM START TO END OF PERIOD
C   OF INTEREST FOR THIS PROGRAM.
C...MOS IS THE NUMBER OF THE MONTH IN WHICH THE EVENT OCCURS.
C...N IS THE NUMBER OF RAINS FOR WHICH DATA WILL BE ENTERED.
C...NNUCS IS THE NUMBER OF PARENT-DAUGHTER NUCLIDE PAIRS PLUS
C   THE NUMBER OF NUCLIDES WHICH WILL BE ENTERED WITH PARENT 'NONE'.
C...LTI IS THE TIME (HR) AT WHICH THE RAIN OCCURS.
C...XP0 IS THE AMOUNT OF RAIN IN A DAY (MM).
C...API IS THE ANTECEDENT PRECIPITATION INDEX (MM), A MEASURE OF THE
C   DEGREE TO WHICH THE GROUND IS SATURATED FROM PREVIOUS RAINS.
C   IT IS CALCULATED USING THE SUMMATION PRESENTED BY SEIVERS.
C...MOR IS THE NUMBER OF THE MONTH IN WHICH THE RAIN OCCURS.
C...SRO IS THE AMOUNT OF PRECIPITATION FROM A DAY'S RAIN
C   WHICH APPEARS AS SURFACE RUNOFF (MM).
C...LHR IS THE NUMBER OF HOURS IN A MONTH.
C...NAMEA AND NAMEB ARE ABBREVIATED NAMES FOR THE
C   PARENT AND DAUGHTER NUCLIDES RESPECTIVELY.
C...THALFA AND THALFB ARE THE RADIOACTIVE HALF-LIVES
C   FOR THE PARENT AND DAUGHTER IN HOURS.
C...XKDA AND XKDB ARE THE DISTRIBUTION COEFFICIENTS
C   FOR PARENT AND DAUGHTER WHICH RELATE THE QUANTITY
C   OF THE NUCLIDES SORBED ON SEDIMENTS TO THE AMOUNT
C   IN WATER SOLUTION AT EQUILIBRIUM (CI/KG / CI/L).
C...GA AND GB RELATE THE INITIAL ACTIVITIES OF PARENT AND
C   DAUGHTER TO THE R/HR AT H+1 HR.  UNITS ARE CI/ R/HR.
C...XLA AND XLB ARE THE RADIOACTIVE DECAY CONSTANTS
C   FOR PARENT AND DAUGHTER (HR-1).
C...AA0 AND AB0 ARE INITIAL ACTIVITIES OF PARENT AND DAUGHTER
C   FALLING AS SEDIMENTS INTO THE STREAM.
```

Figure B-9. WSWCM program listing.

```
C...CA AND CB ARE THE TIME-DEPENDENT ACTIVITY CONCENTRATIONS
C   OF PARENT AND DAUGHTER IN THE STREAM IN THE ABSENCE OF
C   RAIN.  UNITS ARE PCI/L.
C...AWA AND AWB ARE ACTIVITY CONCENTRATIONS OF PARENT AND DAUGHTER IN
C   STREAM WATER AT THE END OF A MONTH.
C...MON IS THE NUMBER OF THE CURRENT MONTH.
C...L IS A COUNTER FOR THE NUMBER OF TIME STEPS.
C...SUMFCA AND SUMFCB ARE THE SUMS OF THE PRODUCTS OF CONCENTRATIONS
C   TIMES FLOW RATES AT A GIVEN TIME FOR THE STEADY FLOWING STREAM
C   AND ANY RUNOFF RAIN WATER FOR PARENT AND DAUGHTER RESPECTIVELY.
C...SUMF IS THE SUM OF THE FLOW RATES FOR THE STEADY FLOWING STREAM
C   AND RUNOFF RAIN WATER AT A GIVEN TIME.
C...NWSP IS THE NUMBER OF THE WATER SUPPLY POINT OF INTEREST FOR THIS RUN.
C
C
      DIMENSION FC(12),SROPE(12),CPT(12),LT1(1ØØ),SSA(1ØØØ),XB(31),
     1XD(31),SSB(1ØØØ),SRO(1ØØ),X(1ØØØ),YA(1ØØØ),YB(1ØØØ),YC(1ØØØ)
      COMMON/C1/B,R,GA,GB,J,XKDA,XKDB
      COMMON/C2/V,XKA,XKB,XL1,XL2,XL3,XL4,EL42,EL21.EL41.
     1EL31,EL43,CA,CB,XLA,XLB,AAØ,ABØ,AWA,AWB
      DATA XB/63.6,13.,12.6,27.1,12.8,28.1,12.2,3Ø.9,13.6,7.9,
     112.4,16.6,9.3,21.4,33.,17.4,1Ø.8,8.4,2Ø.5,22.1,8.7,
     214.3,19.9,31.7,45.3,15.4,9.5,12.5,25.8,24.7,4Ø.2/
      DATA XD/5.8,1.4,3.2,2.7,4.,3.5,3.6.2.,2.5,3.,4.5,5.3,3.2,3.9,7.2,
     13.2,2.3,2.6,3.9,3.3,3.1,3.1,4.,4.6,6.4,2.6,2.,2.7,4.2,4.,4.2/
      DATA FC/3.7,5.Ø,4.9,5.Ø,3.Ø,2.3,1.9,
     11.9,1.9,2.2,3.1,3.4/
      DATA SROPE/.45,.65,.58,.34,.11,.1Ø,.13,
     1.1Ø,.12,.16,.4Ø,.42/
      DATA CPT/8.,4.,5.,9.,12.,12.,13.,
     113.,12.,12.,1Ø.,9./
      INTEGER*4 NAMEA,NAMEB
      OPEN(UNIT=1,NAME='H2O.DAT',TYPE='OLD',READONLY)
      OPEN(UNIT=3,NAME='WATER.DAT',TYPE='NEW')
      OPEN(UNIT=2,NAME='PI.DAT',TYPE='NEW')
      WRITE(3,333)
  333 FORMAT(8X,'INTEGRATED CONCENTRATIONS PCI*DAY/L',//)
C...READ IN NUCLIDE INDEPENDENT DATA.
      READ(1,1)R,LTMAX,NWSP,MOS,N,NNUCS
    1 FORMAT(E1Ø.3,I5,4I2)
      B=XB(NWSP)
      D=XD(NWSP)
      TAU=(D*1ØØØ.)/(Ø.6*36ØØ.)
      BB=Ø.Ø1*B
      XM=BB*1.4E+Ø5
C...READ IN RAIN DATA AND CALCULATE SRO FOR EACH RAIN.
      DO 2Ø I=1,N
      READ(1,7)LT1(I),XPØ,API,MOR
    7 FORMAT(I5,2E1Ø.3,I2)
      APC=API-CPT(MOR)
      IF(APC.GT.Ø.Ø)APC=Ø.Ø
      SRO(I)=SROPE(MOR)*(XPØ+APC)
   2Ø CONTINUE
C...CLEAR GROSS ACTIVITY ARRAY.
      DO 3Ø I=1,1ØØØ
      YC(I)=Ø.Ø
   3Ø CONTINUE
      LHR=729
C...BEGIN NUCLIDE LOOP
      DO 3ØØ I=1,NNUCS
C...INITIALIZE MON FOR EACH PASS THROUGH LOOP.
      MON=MOS
C...READ IN NUCLIDE-DEPENDENT INFORMATION FOR A PARENT DAUGHTER PAIR.
      READ(1,2)NAMEA,THALFA,XKDA,GA
```

Figure B-9. WSWCM program listing (cont).

```
    2 FORMAT(A4,3E1Ø.3)
      READ(1,2)NAMEB,THALFB,XKDB,GB
      XLA=ALOG(2.Ø)/THALFA
      XLB=ALOG(2.Ø)/THALFB
      AAØ=BB*R*GA
      ABØ=BB*R*GB
C...CALL HEAD TO WRITE HEADINGS FOR PLOTS
      CALL HEAD(NAMEA,NAMEB,LTMAX,NWSP)
      L=Ø
      KNTR=-1
      AWA=Ø.Ø
      AWB=Ø.Ø
      CA=Ø.Ø
      CB=Ø.Ø
C...BEGIN OUTER TIME LOOP, WHICH CAUSES THE INNER LOOP TO FIRST GO FROM
C   1 TO 24 IN STEPS OF 1 HR, THEN FROM 27 TO LTMAX IN STEPS OF 3 HR.
      DO 2ØØ IREP=1,3,2
      ISTP=IREP
      IF(ISTP.EQ.1)GO TO 5Ø
      ITF=27
      ITL=LTMAX
      GO TO 51
   5Ø ITF=1
      ITL=24
   51 CONTINUE
C...BEGIN INNER TIME LOOP.
      DO 1ØØ J=ITF,ITL,ISTP
C...CLEAR SUMS FOR EACH TIME STEP
      SUMFCA=Ø.Ø
      SUMFCB=Ø.Ø
      SUMF=Ø.Ø
      LNOW=J/LHR
      IF(LNOW.LE.KNTR)GO TO 111
      KNTR=LNOW
      FMO=FC(MON)
C...CALL RESET TO INITIALIZE VALUES IF IT'S THE FIRST TIME
C   THROUGH AND TO RE-INITIALIZE WHEN IT'S A NEW MONTH.
      CALL RESET(F,XM,LNOW,LHR,FMO,B,TAU,XKDA,XKDB)
C...ADVANCE MON FOR NEXT CALL TO RESET.
      MON=MON+1
      IF(MON.GT.12)MON=1
  111 CONTINUE
      JT=J-LNOW*LHR
C...JT IS NUMBER OF HOURS SINCE START OF PROGRAM OR NEW MONTH.
C...CALL STEADY TO CALCULATE CONCENTRATIONS IN STEADY STREAM FLOW

      CALL STEADY(JT)
      SUMFCA=CA*F
      SUMFCB=CB*F
      SUMF=F
C...CALL RAIN TO CALCULATE THE CONCENTRATIONS AND ASSOCIATED
C   FLOW RATES INTO THE STREAM FOR EACH RAIN AT TIME J.
      DO 6Ø K=1,N
      LT=LT1(K)
      IF(K.GT.1)LT=LT1(K)-LT1(K-1)
      IF(J.GE.LT1(K).AND.(J-LT1(K)).LE.96)
     1CALL RAIN(K,LT,LT1(K),SRO(K),SUMFCA,SUMFCB,SUMF,XLA,XLB)
   6Ø CONTINUE
      CONA=SUMFCA/SUMF
      CONB=SUMFCB/SUMF
C...CONA AND CONB ARE THE TIME-DEPENDENT ACTIVITY CONCENTRATIONS OF
C   PARENT AND DAUGHTER IN THE STREAM INCLUDING THE CONTRIBUTIONS
C   FROM RAINS.
C...SAMPLE WRITES FOR THOSE NOT PLOTTING
```

Figure B-9. WSWCM program listing (cont).

```
C      WRITE(3,3)NAMEA,J,CONA
C      WRITE(3,3)NAMEB,J,CONB
     3 FORMAT(1X,'CONCENTRATION OF',A4,' AT TIME',I5,
      1' HOURS IS',E12.5,' PCI/L')
       L=L+1
       X(L)=J
       IF(CONA.LT.1.ØE-21)CONA=1.ØE-21
       YA(L)=CONA
       IF(CONB.LT.1.ØE-21)CONB=1.ØE-21
       YB(L)=CONB
       CONT=CONA+CONB
       YC(L)=YC(L)+CONT
   1ØØ CONTINUE
   2ØØ CONTINUE
C...SET UP CALLS TO SUM FOR INTEGRATED CONCENTRATIONS.
       SUMA=Ø.Ø
       SUMB=Ø.Ø
       SSA(1)=Ø.Ø
       IF(GA.EQ.Ø.Ø)GO TO 2Ø1
       CALL SUM(YA(1),1.Ø,24,SA1)
       SUMA=SA1/24.
       SSA(1)=SUMA
C      WRITE(3,298)NAMEA,SUMA
   2Ø1 CONTINUE
       CALL SUM(YB(1),1.Ø,24,SB1)
       SUMB=SB1/24.
       SSB(1)=SUMB
C      WRITE(3,298)NAMEB,SUMB
   298 FORMAT(1X,'INTEGRATED CONCENTRATION OF ',A4,' AT DAY    1 IS',
      1E12.5,' PCI*DAY/L')
       DO 91 LDAY=2,LTMAX/24
       LOC=24+((LDAY-2)*8)
       SSA(LDAY)=Ø.Ø
       IF(GA.EQ.Ø.Ø)GO TO 2Ø2
       CALL SUM(YA(LOC),3.Ø,9,SA)
       SA=SA/24.
       SUMA=SUMA+SA
       SSA(LDAY)=SUMA
C      WRITE(3,299)NAMEA,LDAY,SUMA
   2Ø2 CONTINUE
       CALL SUM(YB(LOC),3.Ø,9,SB)
       SB=SB/24.
       SUMB=SUMB+SB
       SSB(LDAY)=SUMB
C      WRITE(3,299)NAMEB,LDAY,SUMB
   299 FORMAT(1X,'INTEGRATED CONCENTRATION OF ',A4,' AT DAY',I5,
      1' IS',E12.5,' PCI*DAY/L')
    91 CONTINUE
C...CALL TAIL TO DO FINAL WRITES TO PLOT FILES
       II=1
       CALL TAIL(L,X,YA,YB,YC,LTMAX,II,NNUCS,NAMEA,NAMEB,LDAY,SSA,SSB,
      1NWSP)
   3ØØ CONTINUE
       CLOSE(UNIT=2,DISP='SAVE')
       CLOSE(UNIT=1)
       CLOSE(UNIT=3,DISP='SAVE')
       STOP
       END
C
C
       SUBROUTINE RESET(F,XM,LNOW,LHR,FMO,B,TAU,XKDA,XKDB)
       COMMON/C2/V,XKA,XKB,XL1,XL2,XL3,XL4,EL42,EL21,EL41,
      1EL31,EL43,CA,CB,XLA,XLB,AAØ,ABØ,AWA,AWB
C
```

Figure B-9. WSWCM program listing (cont).

```
C...SUBROUTINE TO INITIALIZE VALUES AT START OF PROGRAM AND
C   BEGINNING OF EACH NEW MONTH.
C
      IF(LNOW.LT.1)GO TO 1Ø
      AWA=CA*V/1.ØE+12
      AWB=CB*V/1.ØE+12
C...AWA AND AWB ARE ACTIVITIES OF PARENT AND DAUGHTER IN STREAM
C   WATER AS COMPUTED AT THE LAST TIME STEP IN PREVIOUS MONTH.
      E1HR=-XL1*LHR
      IF(E1HR.LT.-5Ø.)E1HR=-5Ø.
      E1HR=EXP(E1HR)
      E2HR=-XL2*LHR
      IF(E2HR.LT.-5Ø.)E2HR=-5Ø.
      E2HR=EXP(E2HR)
      ABØ=(XLB*AAØ/(XL2-XL1))*(E1HR-E2HR)+ABØ*E2HR
      AAØ=AAØ*E1HR
C...AAØ AND ABØ SET TO ACTIVITIES OF PARENT AND DAUGHTER IN SEDIMENTS
C   AFTER ONE MONTH OF DECAY AND INGROWTH.
   1Ø CONTINUE
      F=FMO*B
      V=F*TAU*36ØØ.
      XKA=ALOG(1.Ø+V/(XKDA*XM))/TAU
      XKB=ALOG(1.Ø+V/(XKDB*XM))/TAU
      XL1=XLA+XKA
      XL2=XLB+XKB
      XL3=XLA+1.Ø/TAU
      XL4=XLB+1.Ø/TAU
      EL42=XL4-XL2
      EL21-XL2-XL1
      EL41=XL4-XL1
      EL31=XL3-XL1
      EL43=XL4-XL3
      RETURN
      END
C
C
      SUBROUTINE STEADY(JT)
      COMMON/C2/V,XKA,XKB,XL1,XL2,XL3,XL4,EL42,EL21,EL41,
     1EL31,EL43,CA,CB,XLA,XLB,AAØ,ABØ,AWA,AWB
C
C...SUBROUTINE TO CALCULATE CONCENTRATIONS IN STEADY FLOWING STREAM.
C
      E1=(-XL1*JT)
      IF(E1.LT.-5Ø.)E1=-5Ø.
      E1=EXP(E1)
      E2=(-XL2*JT)
      IF(E2.LT.-5Ø.)E2=-5Ø.
      E2=EXP(E2)
      E3=(-XL3*JT)
      IF(E3.LT.-5Ø.)E3=-5Ø.
      E3=EXP(E3)
      E4=(-XL4*JT)
      IF(E4.LT.-5Ø.)E4=-5Ø.
      E4=EXP(E4)
      TERM1=XLB*XKB*AAØ/EL21
      TERM2=E1/EL41-E2/EL42
      TERM3=XKB*ABØ*E2/EL42
      TERM4=XLB*XKA*AAØ/EL31
      TERM5=E1/EL41-E3/EL43
      TERM6=XLB*AWA*E3/EL43
      TERM7=(1.Ø/EL41-1.Ø/EL42)
      TERM8=XKB*ABØ/EL42
      TERM9=(1.Ø/EL41-1.Ø/EL43)
      TERM1Ø=XLB*AWA/EL43
```

Figure B-9. WSWCM program listing (cont).

```
      ELCB=AWB-(TERM1*TERM7+TERM8+TERM4*TERM9+TERM10)
      CB=(1.0E+12/V)*(TERM1*TERM2+TERM3+TERM4*TERM5+TERM6+ELCB*E4)
      CA=(1.0E+12/V)*((XKA*AA0/EL31)*(E1-E3)+AWA*E3)
      RETURN
      END
C
C
      SUBROUTINE RAIN(K,LT,LT1,SRO,SUMFCA,SUMFCB,SUMF,XLA,XLB)
C
C...SUBROUTINE TO CALCULATE TIME-DEPENDENT CONCENTRATIONS OF PARENT AND
C   DAUGHTER IN RUNOFF RAIN WATER.
C
      COMMON /C1/B,R,GA,GB,J,XKDA,XKDB
      DIMENSION AA(100),AB(100)
      V1=SRO*B*1.0E+06
C...V1 IS THE VOLUME OF WATER (L) ASSOCIATED WITH A GIVEN RAIN
C   = MM*(M/10**3 MM)*(AREA IN KM**2)*(10**6 M**2/KM**2)*10**3 L/M**3
      XM1=.99*B*1.4E+05
C...XM1 IS THE MASS OF 100 MICRON PARTICLES WITH A DENSITY OF 1.4 G/CM**3
C   COVERING THE SURFACE OF THE WATERSHED OUTSIDE THE STREAM BED.
      IF(K.GT.1)GO TO 71
      AA(K)=R*0.99*B*GA
      AB(K)=R*0.99*B*GB
C...AA(1) AND AB(1) ARE THE ACTIVITIES OF PARENT AND DAUGHTER ASSOCIATED
C   WITH PARTICLES AT THE START OF THE PROGRAM.
   71 CONTINUE
C...SET A1A AND A1B TO ACTIVITIES LEFT IN SEDIMENT AFTER LAST RAIN.
      A1A=AA(K)
      A1B=AB(K)
      ELA=-XLA*LT
      IF(ELA.LT.-50.)ELA=-50.
      ELA=EXP(ELA)
      ELB=-XLB*LT
      IF(ELB.LT.-50.)ELB=-50.
      ELB=EXP(ELB)
      A1B=(XLB/(XLB-XLA))*A1A*(ELA-ELB)+A1B*ELB
      A1A=A1A*ELA
C...A1A AND A1B ARE NOW DECAYED TO TIME OF PRESENT RAIN.
C...E1A AND E1B ARE ACTIVITIES LEACHED INTO RUNOFF WATER.
      E1A=A1A/(1+XKDA*XM1/V1)
      E1B=A1B/(1+XKDB*XM1/V1)
C...JT1 IS TIME FROM START OF THIS RAIN TO PRESENT TIME STEP.
      JT1=J-LT1
      E1LA=-XLA*(JT1)
      IF(E1LA.LT.-50.)E1LA=-50.
      E1LA=EXP(E1LA)
      E1LB=-XLB*(JT1)
      IF(E1LB.LT.-50.)E1LB=-50.
      E1LB=EXP(E1LB)
C...C1A AND C1B ARE ACTIVITY CONCENTRATIONS IN RUNOFF WATER AT TIME J.
      C1B=(1.0E+12/V1)*((XLB*E1A/(XLB-XLA))*(E1LA-E1LB)+E1B*E1LB)
      C1A=(1.0E+12/V1)*E1A*E1LA
C...SET AA AND AB TO ACTIVITIES LEFT IN SEDIMENT AFTER THIS RAIN.
      AA(K+1)=A1A-E1A
      AB(K+1)=A1B-E1B
C...CALL FLOW TO CALCULATE FLOW RATE INTO STREAM FOR RUNOFF
C   FROM THIS RAIN AT TIME J.
      CALL FLOW(SRO,F1,JT1)
C     WRITE(3,72)JT1,C1A,C1B,F1
   72 FORMAT(1X,'J-LT1 =',I3,' C1A =',E12.5,' C1B =',E12.5,'F1 =',E12.5)
C...ADD CONTRIBUTIONS FROM THIS RAIN TO PREVIOUS SUMS
      SUMFCB=SUMFCB+C1B*F1
      SUMFCA=SUMFCA+C1A*F1
      SUMF=SUMF+F1
```

Figure B-9. WSWCM program listing (cont).

```
      RETURN
      END
C
C
      SUBROUTINE FLOW(SRO,F1,JT1)
C
C...SUBROUTINE TO CALCULATE THE TIME-DEPENDENT FLOW RATE INTO
C   THE STREAM FOR CONTAMINATED RUNOFF RAIN WATER.
C
      EP3=-.3Ø11*JT1
      IF(EP3.LT.-5Ø.)EP3=-5Ø.
      EP3=EXP(EP3)
      EPØ3=-.ØØ48*JT1
      IF(EPØ3.LT.-5Ø.)EPØ3=-5Ø.
      EPØ3=EXP(EPØ3)
      F1=-SRO*11.39*(EP3-EPØ3)
      RETURN
      END
C
C
      SUBROUTINE SUM(Y,DX,NO,S)
C
C..TRAPEZOIDAL INTEGRATION ROUTINE FOR COMPUTING INTEGRATED
C..CONCENTRATIONS IN PCI*DAY/L
C
      DIMENSION Y(1)
C... Y ARRAY HAS F(I) VALUES
C... DX = EQUAL DISTANCE DELTA X VALUES (TIMESTEPS)
      S=Ø.Ø
      DO 1 I=2,NO
    1 S=S+((Y(I)+Y(I-1))/2.Ø)*DX
      RETURN
      END
C
C
      SUBROUTINE HEAD(NAMEA,NAMEB,LTMAX,NWSP)
C
C...ROUTINE TO SET UP HEADINGS ON PLOTS
C
      INTEGER*4 NAMEA,NAMEB
      WRITE(2,8)NAMEB,NWSP
    8 FORMAT(3X,'7Ø',14X,A4,1X,'WATER CONTAMINATION WSP #',I2)
      WRITE(2,9)NAMEA
    9 FORMAT(3X,'7Ø',23X,'PARENT IS ',A4)
      WRITE(2,1Ø)NAMEB
   1Ø FORMAT(3X,'35',A4,1X,'CONCENTRATION IN WATER (PCI/L)')
      WRITE(2,11)
   11 FORMAT(3X,'31TIME SINCE INITIAL FALLOUT (HR)')
      WRITE(2,12)
   12 FORMAT(9X,'Ø',9X,'1',9X,'2',9X,'3')
      WRITE(2,13)
   13 FORMAT(4X,'2 ')
      WRITE(2,17)
   17 FORMAT(1X,'3',1X,'1Ø.',1X,'13.',1X,'.65Ø')
      WRITE(2,14)LTMAX
   14 FORMAT(1X,'Ø.Ø',1X,I5)
      WRITE(2,15)
   15 FORMAT(1X,'9.E+Ø6',1X,'1.ØE+ØØ')
      RETURN
      END
C
C
      SUBROUTINE TAIL(L,X,YA,YB,YC,LTMAX,II,NNUCS,
     1NAMEA,NAMEB,LDAY,SSA,SSB,NWSP)
```

Figure B-9. WSWCM program listing (cont).

```
C
C...ROUTINE TO WRITE DATA ARRAYS TO PLOT FILE
C
      DIMENSION X(1),YA(1),YB(1),YC(1),SSA(1),SSB(1)
      INTEGER*4 NAMEA,NAMEB
      WRITE(3,30)NAMEA,NAMEB
   30 FORMAT(/,10X,'DAY',7X,A4,10X,A4,/)
      DO 40 K=1,LDAY
      WRITE(3,222)K,SSA(K),SSB(K)
  222 FORMAT(8X,I5,' ...',1P,E10.3,' ...',E10.3)
   40 CONTINUE
      WRITE(2,4)L
      WRITE(2,*)(X(LL),LL=1,L)
      WRITE(2,*)(YA(LL),LL=1,L)
      WRITE(2,5)L
      WRITE(2,*)(X(LL),LL=1,L)
      WRITE(2,*)(YB(LL),LL=1,L)
    5 FORMAT(I5,'     1     4     5')
    4 FORMAT(I5,'     1     4     1')
      WRITE(2,6)
    6 FORMAT(1X,'0')
      I=II
      IF(I.LT.NNUCS)RETURN
C...FINISHED WITH ALL NUCLIDES. SET UP PLOT OF GROSS ACTIVITY
      WRITE(2,19)NWSP
   19 FORMAT(3X,'70',14X,'TOTAL WATER CONTAMINATION WSP #',I2)
      WRITE(2,21)
   21 FORMAT(3X,'70',15X,'SUMMED OVER ALL NUCLIDES')
      WRITE(2,22)
   22 FORMAT(3X,'31GROSS ACTIVITY IN WATER (PCI/L)')
      WRITE(2,11)
   11 FORMAT(3X,'31TIME SINCE INITIAL FALLOUT (HR)')
      WRITE(2,12)
   12 FORMAT(9X,'0',9X,'1',9X,'2',9X,'3')
      WRITE(2,23)
   23 FORMAT(1X,'1')
      WRITE(2,17)
   17 FORMAT(1X,'3',1X,'10.',1X,'13.',1X,'.650')
      WRITE(2,14)LTMAX
   14 FORMAT(1X,'0.0',1X,I5)
      WRITE(2,25)
   25 FORMAT(1X,'9.E+07',1X,'1.0E+02')
      WRITE(2,5)L
      WRITE(2,*)(X(LL),LL=1,L)
      WRITE(2,*)(YC(LL),LL=1,L)
      WRITE(2,6)
      RETURN
      END
```

Figure B-9. WSWCM program listing (cont).

```
....  A PLOT OF Y VS. X ON LIN(LOG1Ø)-LIN(LOG1Ø) FOR
      [illegible] AND ON A ROTATED [illegible]
      [illegible]
    D[illegible] X([illegible]),Y([illegible]),LP[illegible],YMARK(1Ø),TYPE(5),IPTYPE(7)
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible] TITLE
      [illegible]
      [illegible] OF [illegible] IN EACH NAME

      [illegible] Y [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible] GRID
      [illegible] DECADES
      [illegible]
      [illegible] INTERGER
      [illegible] 1.[illegible].5,1.75,2.5,3.5,4.5,5.5
      FO[illegible]
      [illegible] GRID
      [illegible] UNIT GRID

      [illegible] A PLAIN OLD CURVE
      [illegible] Y [illegible] IGNORED)
      [illegible] WITH SYMBOLS TOO
      [illegible]
      [illegible]
      [illegible] WITH SYMBOLS

      FO[illegible]
      [illegible]
      [illegible] CU[illegible]
      [illegible]
      [illegible]
      [illegible]
      FO[illegible]S
      [illegible] VE[illegible]LOT MANUAL (PAGE [illegible])

      [illegible]

   5   1Ø    [illegible]   [illegible]   [illegible]   5[illegible]   [illegible]   7Ø(COLUMNS)
---- ---- -------- ---------------------------------------------------------------
LNG1   [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
      IPT[illegible]
[illegible]
      [illegible] (NOTE:IF [illegible]IST>1 ITYPE=CURVE+1Ø*SY[illegible])
THE X [illegible] ECTED [illegible]
[illegible]
[illegible]
[illegible] ON [illegible] CARDS [illegible]
```

Figure B-10. Data plot program listing.

```
THE Y DATA LIST DIRECTED
* * * *
```

Figure B-10. Data plot program listing (cont).

```
      XMIN=X(1)
      XMAX=X(1)
      [illegible]
      [illegible]
      [illegible],NPT
      [illegible](I)) XMAX=X(I)
      [illegible]
      [illegible]
15    [illegible]
      [illegible]

      [illegible]
C     ...RANGE [illegible] XMIN AND YMIN VALUE IN THE X AND Y ARRAYS
C     [illegible] T TO NEXT LOWEST VALUE.  IF IX OR IY NOT = 0.
      [illegible] GO TO 1[illegible]
      [illegible] LOAT(INT( MIN-1.0))
      [illegible]
      [illegible]MIN)+1.0
      [illegible]
      [illegible]UNITY+0.00
      [illegible] XAX
 21   [illegible]WARNING, AXIS LNGTH CH[illegible]GED TO',F4.1/15X,
     / [illegible] IS GREATER THAN 8 INCHES YOU [illegible] HAVE PROBLEMS')
C     ..........................
      [illegible] TO 1[illegible]
      [illegible]LOAT(INT(YMIN-1.0))
      [illegible]
      [illegible]MIN))+1.0
      [illegible]
      [illegible]/YAX
      [illegible]UNIT+0.0
      [illegible] YAX
 200  [illegible].....WARNING,YAXIS LNGTH CHANGED TO',F4.1/15X,
     / [illegible] LARGER THAN 10 INCHES YOU MAY HAVE PROBLEMS')
C     [illegible] AND PLOT THE DATA.
      [illegible]
      [illegible]
      [illegible] LL AXIS(0.,[illegible],XAX,0.,X(NPT+1),X(NPT+2))
      [illegible] 1[illegible]
      [illegible]
      [illegible](DST(I))*UNITY
      [illegible] AX
      [illegible]
      [illegible](I-1) 1
      [illegible] TO [illegible]
C     ....                ..........
```

Figure B-10. Data plot program listing (cont).

```
      YNEW=Ø.[illegible]
      CALL PLOT(YAX,YNEW,3)
      [illegible] SYMBOL([illegible],YNEW,Ø.1,15,Ø.Ø,-2)
      [illegible]
      [illegible] S[illegible]((I-1)*UNITX,(YNEW-.ØØ),.2,16,Ø.Ø,-1)
      [illegible]((I-1)*UNITX-.1,(YNEW-.42),.12,TEN,Ø.Ø,-1)
      [illegible]=.1[illegible](I-1)*UNIT[illegible]
      [illegible]=FLOAT(LPOW(I))
      [illegible]((XHYT),(YNEW-.3),.Ø9,POWR,Ø.Ø,-1)
      [illegible] GO TO 65
      [illegible]1,3
      [illegible](M)+(I-1)*UNITX
      [illegible](XMARK,YNEW-.ØØØ),.15,16,Ø.Ø,-1)
 5    CONTINUE
      [illegible]-[illegible].125)/2.Ø
      CALL SYMBOL(XID,-.8,.125,NAMEX,Ø.Ø,LNGX)
.............................................
 3    IF(IV.EQ.Ø)CALL AXIS(Ø.,Ø.,NAMEY,LNGY,YAX,9Ø.,Y(NPT+1),Y(NPT+2))
      IF(IV.EQ.1) GO TO 1[illegible]
      DO 35 I=2,19
 35   [illegible](I-1)=ALOG1Ø(FLOAT(I))*UNIT
      [illegible] UNIT IS LARGER THAN YAX.
      [illegible](1)=Y[illegible]
      DO [illegible] I=2,[illegible]
      L[illegible]=I-1
      L[illegible](I)=L[illegible](I-1)+1
      [illegible]=(I-1)*UNIT
      IF([illegible].YAX) GO TO 41
 40   CONTINUE
......[illegible] GO........
 41   CONTINUE
      DO 45 IREP=1,2
      [illegible]=(IREP-1)*YAX
...   [illegible] ADJUSTED Y AXIS.
      CALL PLOT([illegible]NEW,YAX,3)
      CALL SYMBOL(XNEW,Ø.Ø,Ø.1,16,Ø.Ø,-2)
      DO 45 I=1,LINY
      CALL SYMBOL((XNEW-.ØØ-.12*(IREP-1)),(I-1)*UNIT,.2,15,Ø.Ø,-1)
      CALL [illegible]((XNEW-.6+.6*(IREP-1)),(I-1)*UNIT,.12,TEN,Ø.Ø,-1)
      [illegible]=.12+(I-1)*UNIT
      [illegible]=FLOAT(LPOW(I))
      CALL NUMBER((XNEW-.3+.6*(IREP-1)),YHYT,.Ø9,POWR,Ø.Ø,-1)
      IF(I.EQ.LINY) GO TO 45
      DO 45 M=1,8
      [illegible]=YMARK(M)+(I-1)*UNIT
      CALL SYMBOL((XNEW-.ØØØ-.Ø75*(IREP-1)),TYMARK,.15,15,Ø.Ø,-1)
 45   CONTINUE
.............................................
      YID=[illegible]-[illegible]*.125)/2.Ø
      CALL SYMBOL(-.7,YID,.125,NAMEY,9Ø.Ø,LNGY)
 4    CALL SYMBOL(.25,YAX+.5,.15,NAME1,Ø.Ø,LNG1)
      CALL SYMBOL([illegible],YAX+.15,.125,NAME2,Ø.Ø,LNG2)
      [illegible]
      [illegible]
      [illegible]
      [illegible]

  TH[illegible] ATTEMPT..........!!!!!!!!!!!????????????************

      [illegible].AND.IGRIDY.EQ.Ø)GO TO 6ØØ
      [illegible]
      [illegible]
      [illegible]
      [illegible].LMASK2,LMASK3
```

Figure B-10. Data plot program listing (cont).

```
      IF(IGRIDX.EQ.Ø)GO TO 5Ø1
      KXX=Ø
      KX=1
      XX(1)=UNITX
      IF(IX.EQ.Ø) XX(1)=1.
      GO TO 51Ø
5Ø1   KXX=1
      KX=Ø
      XX(1)=UNITX*(LIMX-1)
      IF(IX.EQ.Ø)XX(1)=(LIMX-1.)
51Ø   IF(IGRIDY.EQ.Ø)GO TO 511
      KYY=Ø
      KY=1
      YY(1)=UNIT
      IF(IY.EQ.Ø)YY(1)=1.
      GO TO 52Ø
511   KYY=1
      KY=Ø
      YY(1)=(LIMY-1)*UNIT
      IF(IY.EQ.Ø)YY(1)=(LIMY-1.)
52Ø   CALL GRID(Ø.Ø,Ø.Ø,KX*(LIMX-1)+KXX,XX,KY*(LIMY-1)+KYY,YY,LMASK1)
      IF(IGRIDX.LE.2)GO TO 521
      KX=9
      KXX=1ØØØ
      DO 522 I=1,LIMX
      DO 523 J=1,9
523   XX((I-1)*9+J)=UNITX*(ALOG1Ø(J+1.)-ALOG1Ø(J+Ø.))
522   CONTINUE
      GO TO 53Ø
521   IF(IGRIDX.LT.2) GO TO 524
      [illegible]
      KXX=1ØØØ
      DO 525 I=1,LIMX
      XX(I*4-3)=UNITX*(ALOG1Ø(2.)-ALOG1Ø(1.))
      XX(I*4-2)=UNITX*(ALOG1Ø(3.)-ALOG1Ø(2.))
      XX(I*4-1)=UNITX*(ALOG1Ø(6.)-ALOG1Ø(3.))
      XX(I*4-Ø)=UNITX*(ALOG1Ø(1Ø.)-ALOG1Ø(6.))
525   CONTINUE
      GO TO 53Ø
524   KXX=1
      [illegible]
      XX(1)=UNITX*(LIMX-1)
      IF(IX.EQ.Ø)XX(1)=1./IGRDX
      IF(IX.EQ.Ø)KXX=Ø
      IF(IX.EQ.Ø)KX=IGRDX
53Ø   IF(IGRIDY.LE.2)GO TO 531
      [illegible]
      KYY=1ØØØ
      DO 532 I=1,LIMY
      DO 533 J=1,9
533   YY((I-1)*9+J)=UNIT*(ALOG1Ø(J+1.)-ALOG1Ø(J+Ø.))
      [illegible]
      [illegible]
531   IF(IGRIDY.LT.2)GO TO 534
      [illegible]
      [illegible]
      DO 535 I=1,LIMY
      YY(I*4-3)=UNIT*(ALOG1Ø(2.)-ALOG1Ø(1.))
      YY(I*4-2)=UNIT*(ALOG1Ø(3.)-ALOG1Ø(2.))
      YY(I*4-1)=UNIT*(ALOG1Ø(6.)-ALOG1Ø(3.))
      YY(I*4-Ø)=UNIT*(ALOG1Ø(1Ø.)-ALOG1Ø(6.))
535   CONTINUE
      GO TO 54Ø
534   [illegible]
```

Figure B-10. Data plot program listing (cont).

```
      KYY=1
      YY(1)=UNIT*(LIMY-1)
      [illegible]YY(1)=1./IGRDY
      [illegible]
      [illegible]IGRDY
 40   [illegible],KX*(LIMX-1)+KXX,XX,KY*(LIMY-1)+KYY,YY,LMASK2)
 50   [illegible].3)GO TO 551
      [illegible]
      [illegible] I=1,LIMX
      [illegible] J [illegible],5
 53   [illegible])-UNITX*(ALOG10(J+.5)-ALOG10((J-1.)+.5))
      [illegible](ALOG10(1.5)-ALOG1[illegible](1.0))
      [illegible]ALOG10(10.)-ALOG10(5.5))
 52   [illegible]
 51   [illegible]
      [illegible]UNITX*(LIMX-1.)
      [illegible]=(LIMX-1.)
 50   [illegible].3)GO TO 561
      [illegible]
      [illegible] I=1,LIMY
      [illegible],5
 53   [illegible]IT*(ALOG10(J+.5)-ALOG10((J-1.)+.5))
      [illegible]ALOG10(1.5)-ALOG10(1.0))
      [illegible]LOG1[illegible](10.)-ALOG10(5.5))
 52   [illegible]
 51   [illegible]
      [illegible]UNIT*(LIMY-1.)
      [illegible]=(LIMY-1.)
 50   [illegible]KX*(LIMX-1)+KXX,XX,KY*(LIMY-1)+KYY,YY,LMASK3)
      [illegible]
      [illegible]1) GO TO 6[illegible]
      [illegible]
      [illegible])+1)
      [illegible]/2)+1)
      [illegible]
      [illegible]1)+YTEMP(3))/2
      [illegible]1)+YTEMP(2))/2
      [illegible] CALL NEWPEN(IPEN)
      [illegible] CALL NEWPEN(IPENØ)
      [illegible],YTEMP,-3,TYP[illegible](MOD(ITYPE,10)))
 04   [illegible]
      [illegible] GO TO [illegible]
 02   [illegible]
      [illegible]
      [illegible]) CALL NEWPEN(IPEN)
      [illegible]) CALL NEWPEN(IPENØ)
      [illegible]=-1
      [illegible].4) LINTYP=0
```

Figure B-10. Data plot program listing (cont).

```
      IF(IHIST.EQ.5) LINTYP=1
      IF(IHIST.EQ.4.OR.IHIST.EQ.5) CALL LINE(X,Y,NPT,1,LINTYP,ITYPE/1Ø)
      IF(NPT.GT.2) GO TO 6Ø3
      [illegible]=X(4)
      [illegible]=X(3)
      [illegible]=X(2)
      [illegible]=(X(1)+X(2))/2.
      [illegible]=Y(4)
      [illegible]=Y(3)
      [illegible]=Y(2)
      [illegible](Y(1)+Y(2))/2.
      [illegible]
ø3    [illegible]IST.EQ.Ø.OR.IHIST.EQ.2) CALL CURVE(X,Y,-1*NPT,
     /   [illegible](ITYPE,1Ø)))
[illegible]   [illegible]
      [illegible]) NSET
      IF(N[illegible]T.EQ.Ø) GO TO 7ØØ
      [illegible] NST=1,NSET
      [illegible]7,*) NPT,ITYPE,IHIST,IPENØ
      [illegible]7,*) (X(I),I=1,NPT)
      [illegible]7,*) (Y(I),I=1,NPT)
      [illegible],NST
'43   [illegible]T(' [illegible]AD SYMBOL NUMBER ',I3)
      [illegible] I=1,NPT
      [illegible].EQ.[illegible]) X(I)=ALOGIØ(X(I))
      [illegible]) Y(I)=ALOGIØ(Y(I))
'15   [illegible]
      [illegible])= SCL1
      [illegible]= SCL2
      [illegible]I)= SCL1
      [illegible]2)= SCL2
      [illegible]) CALL NEWPEN(IPEN)
      [illegible]) CALL NEWPEN(IPENØ)
      [illegible](X,Y,NPT,1,-1,ITYPE)
'ø1   [illegible]
[illegible] [illegible]
      [illegible]PLOT([illegible],-999)
      [illegible]
      [illegible]
1?9   [illegible]
      [illegible]T=7)
      [illegible]PLOT([illegible],999)
      STOP
      [illegible]
      [illegible]UTINE FIN(DEL,SCALE,ZAX)
      [illegible]A(11)
      DATA A/1.,1.5,2.,2.5,3.,4.,5.,6.,7.5,8.,1Ø./
      Z=DEL/ZAX
      LZ=ALOG1Ø(Z)
      [illegible]LT.1) LZ=LZ-1
      [illegible]
      [illegible]
      [illegible]
      [illegible]) GO TO 11
ø
[illegible]   [illegible] LZ
      [illegible]
      END
```

Figure B-10. Data plot program listing (cont).

SECTION B-4

SAMPLE WSWCM PROBLEM

B-4.1 Problem Statement

The watershed of Water Supply Point Number 8 is contaminated on July 4 with a fallout intensity of 1 R/hr at H+1 hour. Determine the water contamination that occurs out to August 14. Use the precipitation data given in Table B-11.

B-4.2 WSWCM Input

The user input requirements for the computer program WSWCM were described earlier in Section B-3.2. Figure B-11 illustrates the sample problem input by giving examples of the basic problem data, the precipitation data for one of the rain events, and the radionuclide data for one of the parent-daughter radionuclide pairs. The sources of the data values used for the sample problem are discussed below. Figure B-12 shows the actual data input for the sample problem.

B-4.2.1 Basic Problem Data

The problem statement specifies that the Fallout Exposure Rate of the Watershed is 1.0 R/hr at H+1 hour, R = 1.0.

The Problem Simulation Time must cover the period of July 4 to August 14; this period is about 999 hours, LTMAX = 999.

The problem statement gave the Identification Number of the Water Supply Point, NWSP = 8.

The month in which the Problem Starts is July, MOS = 7.

Table B-11. Daily precipitation data (mm) - Bad Hersfeld (1972).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1		t		4.9		0.4	0.9	0.2	t			
2				3.4		3.7	3.0	t	0.8			
3	t		0.3	1.3	0.2		0.2	4.9				1.7
4	t	2.5	1.8	10.0	0.7		t	0.9			0.1	0.4
5	t			3.3	0.8			0.1			t	
6		0.4		3.5	t	5.5	1.1				0.3	
7		t	1.1	2.3	0.4	14.0			2.4		t	10.2
8	2.0	t	1.2	1.6	5.4	0.3	0.3	0.6			1.4	
9		t			11.2	2.3	28.6	9.2	t			0.1
10	1.1	1.4	8.9	4.6	13.5	0.4	8.3	2.5	17.9		5.2	
11	0.1	1.7	t	5.5	0.6	20.8		11.3			6.8	0.1
12		t			5.2	5.0			0.1		6.9	
13		0.2		0.9	0.5			0.1			3.4	
14		0.1		t				25.0			t	t
15				7.1	0.1	21.2		16.6			0.2	
16					19.3	1.6		10.7	9.3		t	
17								20.9	9.6		19.5	
18				2.8				0.9	2.5		t	nd
19	t			1.2		5.6		1.6		0.3	1.6	nd
20					t			t		0.6	5.0	nd
21	0.7			12.4	t			0.6		2.8	1.8	nd
22				2.3		8.4	20.9	3.4	0.5	6.8	0.7	nd
23			t		3.7	0.9			t	0.8	6.3	nd
24	0.4				0.7		17.0		0.6		0.9	nd
25	[illegible]			t	1.5		1.0	t	1.0			
26	1.9		3.5	0.7	7.3				2.1	4.3		
27			15.1	0.4	4.6				1.2	0.3	t	
28	t		5.3	0.4	7.8	5.9	1.7			5.2		
29	0.3		1.5		7.0	8.6	4.3					
30	[illegible]		t		6.1	43.7	13.6				t	
31	[illegible]		[illegible]		0.6		3.7					

CARD	Field	Format	Value	REMARKS
1	[illegible]	E10.3	1.[illegible]00E+0[illegible]	Basic Problem Data
1	LTMAX	I5	[illegible]	
1	NWSP	I2	8	
1	NOS	I2	7	
1	N	I2	21	
1	NNUCS	I2	22	
2	LTI(1)	I5	[illegible]	Precipitation Data First Rain
2	[illegible]	E10.3	[illegible]E+[illegible]	
2	API	E10.3	2.[illegible]E+[illegible]	
2	NOR	I2	7	
23	NAMEA	A4	[illegible]M	Radionuclide Data First Parent
23	THALFA	E10.3	[illegible]E+01	
23	XOA	E10.3	1.[illegible]E+02	
23	SA	E10.3	1.3[illegible]E+01	
24	NAMEB	A4	11[illegible]	Radionuclide Data First Daughter
24	THALFB	E10.3	[illegible]E+[illegible]	
24	XOB	E10.3	[illegible]00E+01	
24	SB	E10.3	1.[illegible]0E+01	

Figure B-11. Sample problem input preparation.

```
1.000E 00   999 8 72122
  48 1.100E 00 2.100E 01 7
  96 3.000E-01 1.700E 01 7
 120 2.950E 01 1.500E 01 7
 144 8.300E 00 3.500E 01 7
 432 2.090E 01 9.900E 00 7
 480 1.730E 01 1.700E 01 7
 501 1.000E 03 3.000E 01 7
 576 1.720E 00 2.300E 01 7
 600 4.300E 03 2.000E 01 7
 624 1.360E 01 2.000E 01 7
 648 3.700E 00 2.000E 00 7
 672 2.000E-01 1.700E 01 8
 720 4.900E 00 1.400E 01 8
 744 9.000E-01 1.500E 01 8
 768 1.000E-01 1.500E 01 8
 810 6.000E-01 1.200E 01 8
 864 9.200E 00 1.700E 01 8
 888 2.500E 00 1.300E 01 8
 912 1.130E 01 1.300E 01 8
 960 1.000E-01 1.700E 01 8
 984 2.500E 01 1.700E 01 8
T31M 3.000E 01 1.000E 02 1.300E 01
I131 1.900E 02 1.000E 01 1.500E 01
NONE 1.000E 00 1.000E 00 0.000E 00
I133 2.000E+01 1.000E 01 3.000E 02
TE32 7.600E 01 1.000E 02 7.100E 01
I132 2.000E 02 1.000E 01 3.000E 01
MO99 6.600E 01 2.500E 01 1.000E 02
TC9M 6.200E 00 1.000E 00 0.000E 00
ZR97 1.680E 01 1.000E 03 4.100E 02
NB97 1.200E 00 1.000E 04 2.200E 02
BA40 1.270E 02 5.000E 02 2.400E 01
LA40 4.000E 01 5.000E 02 6.300E-01
NONE 1.000E 00 1.000E 00 0.000E 00
I135 6.700E 00 1.000E 01 9.900E 02
SR91 9.700E 00 1.000E 03 6.600E 02
Y 91 1.400E 03 1.000E 03 2.100E-01
CE43 3.300E 01 1.000E 04 2.000E 02
PR43 1.300E 02 1.000E 04 3.000E-01
NONE 1.000E 00 1.000E 00 0.000E 00
SR89 1.210E 03 1.000E 03 4.100E 00
SR90 1.100E 01 1.000E 01 2.200E 00
TE27 9.400E 00 1.000E 02 0.000E 00
ZR95 1.500E 03 1.000E 03 4.800E 00
NB95 3.400E 01 1.000E 04 3.000E-03
ND47 2.600E 02 1.000E 04 1.100E 01
PM47 [illegible] 04 1.000E 04 [illegible] 00
RU03 1.440E 00 5.000E 03 2.700E 02
RH03 3.500E 01 1.000E 03 5.700E 00
CE44 6.820E 03 1.000E 04 9.400E-01
PR44 2.880E-01 1.000E 04 0.000E 00
SR90 1.040E 05 1.000E 01 1.700E-02
Y 90 1.400E 01 1.000E 03 5.000E-03
RU03 9.456E 02 5.000E 03 4.200E 00
RH03 1.000E-01 5.000E 03 0.000E 00
NONE 1.000E 00 1.000E 00 0.000E 00
CS37 2.840E 05 1.000E 03 2.800E-01
T29M 8.016E 02 1.000E 02 7.000E-02
TE29 1.167E 00 1.000E 02 0.000E 00
RU06 8.832E 03 5.000E 03 7.900E-02
RH06 [illegible]-03 5.000E 03 0.000E 00
NONE [illegible] 0.000E 00
CE41 7.000E 02 1.000E 04 9.300E-01
NONE 1.000E 00 1.000E 00 0.000E 00
I134 9.000E-01 1.000E 01 4.400E 02
```

Figure B-12. Sample problem input.

The Number of Rains during the Problem Simulation Time, from July 4 to August 14, is determined from Table B-11, N = 21.

The Number of Parent-Daughter Radionuclide Pairs included in Table B-1 is 22, NNUCS = 22.

B-4.2.2 Precipitation Data

The precipitation data to be used in the sample problem is given in Table B-11. Between July 4 and August 14 there are 21 rain events. The procedure for developing the precipitation data for WSWCM can be shown by considering the first rain event.

The first rain event occurs on July 6, this is 2 days after the problem starts; the Time at which the 1st Rain Occurs is thus 48 hours, LT1(1) = 48.

As seen in Table B-11, the Amount of Precipitation in the 1st Rain is 1.1 mm, XPO = 1.1.

The Antecedent Precipitation Index for the 1st Rain is calculated using the method given in Section B-2.4.2. An example of this calculation is given in Table B-12, API = 21.

The Month in which the 1st Rain Occurs is July, MOR = 7.

B-4.2.3 Radionuclide Data

The set of data presented in Table B-1 includes 22 parent-daughter radionuclide pairs. The procedure for developing the radionuclide data for WSWCM can be shown by considering the radionuclide Te-131m (from the Te-131m, I-131 pair) as the first parent radionuclide.

The Identification Name of the 1st Parent Radionuclide is an abbreviation of Te-131m, NAMEA = T31M.

Table B-12. Antecedent precipitation index calculation.
(Example for July 6)

Day	n	Po-n	$P_{o-n} \times (0.9)^n$	$\sum_n P_{o-n} \times (0.9)^n$
July 6	na	na	na	na
5	1	-	0.00	0.00
4	2	-	0.00	0.00
3	3	0.2	0.14	0.14
2	4	3.0	1.97	2.11
1	5	0.9	0.53	2.65
June 30	6	43.7 but use 13.0	6.91	9.55
29	7	8.6	4.11	13.7
28	8	5.9	2.54	16.2
27	9	-	0.00	16.2
26	10	-	0.00	16.2
25	11	-	0.00	16.2
24	12	-	0.00	16.2
23	13	0.9	0.23	16.4
22	14	8.4	1.92	18.4
21	15	-	0.00	18.4
20	16	-	0.00	18.4
19	17	5.6	0.94	19.3
18	18	-	0.00	19.3
17	19	-	0.00	19.3
16	20	1.6	0.19	19.5
15	21	21.2 but use 12.0	1.31	20.8

The Radioactive Half-Life of the 1st Parent Radionuclide is the half-life of Te-131m; the value can be found in numerous nuclear data reference books, THALFA = 30.

The Distribution Coefficient of the 1st Parent Radionuclide is the Kd value for Te given in Table B-7, XKDA = 100.

The Normalized Ground Concentration of the 1st Parent Radionuclide is the value given in Table B-1 for Te-131m, GA = 13.

B-4.3 WSWCM Output

The output provided by the computer program WSWCM for the sample problem includes:

- o 22 plots, one for each parent-daughter radionuclide pair, of the radionuclide concentration in water as a function of time (Figures B-13 to B-34),
- o 1 plot of the composite, or total, radionuclide concentration in water as a function of time (Figure B-35), and
- o 1 tabular listing of the time-integrated radionuclide concentration in water as a function of time for the parent-daughter radionuclide pairs (Table B-13).

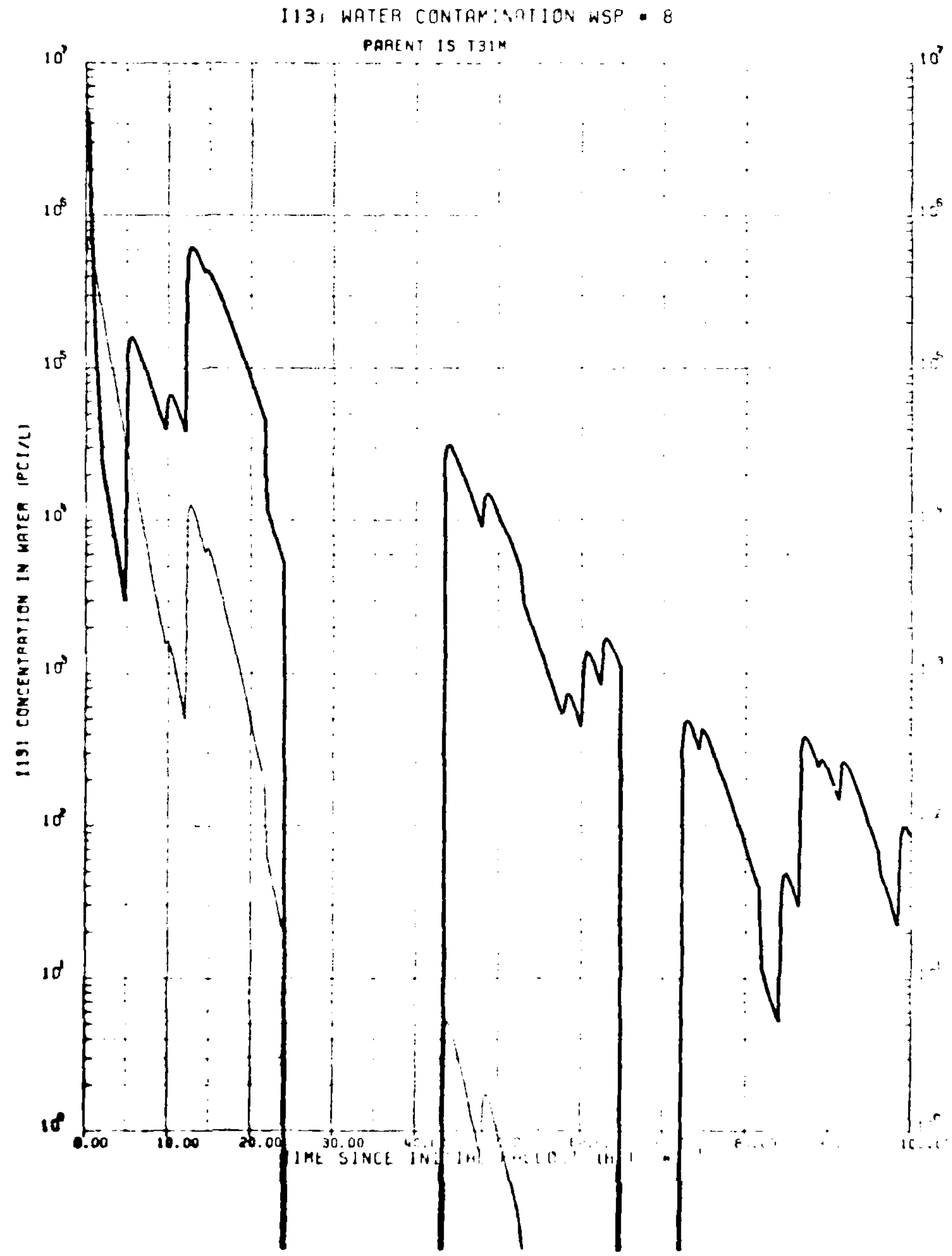


Figure B-13. Te-131m, I-131 water contamination.

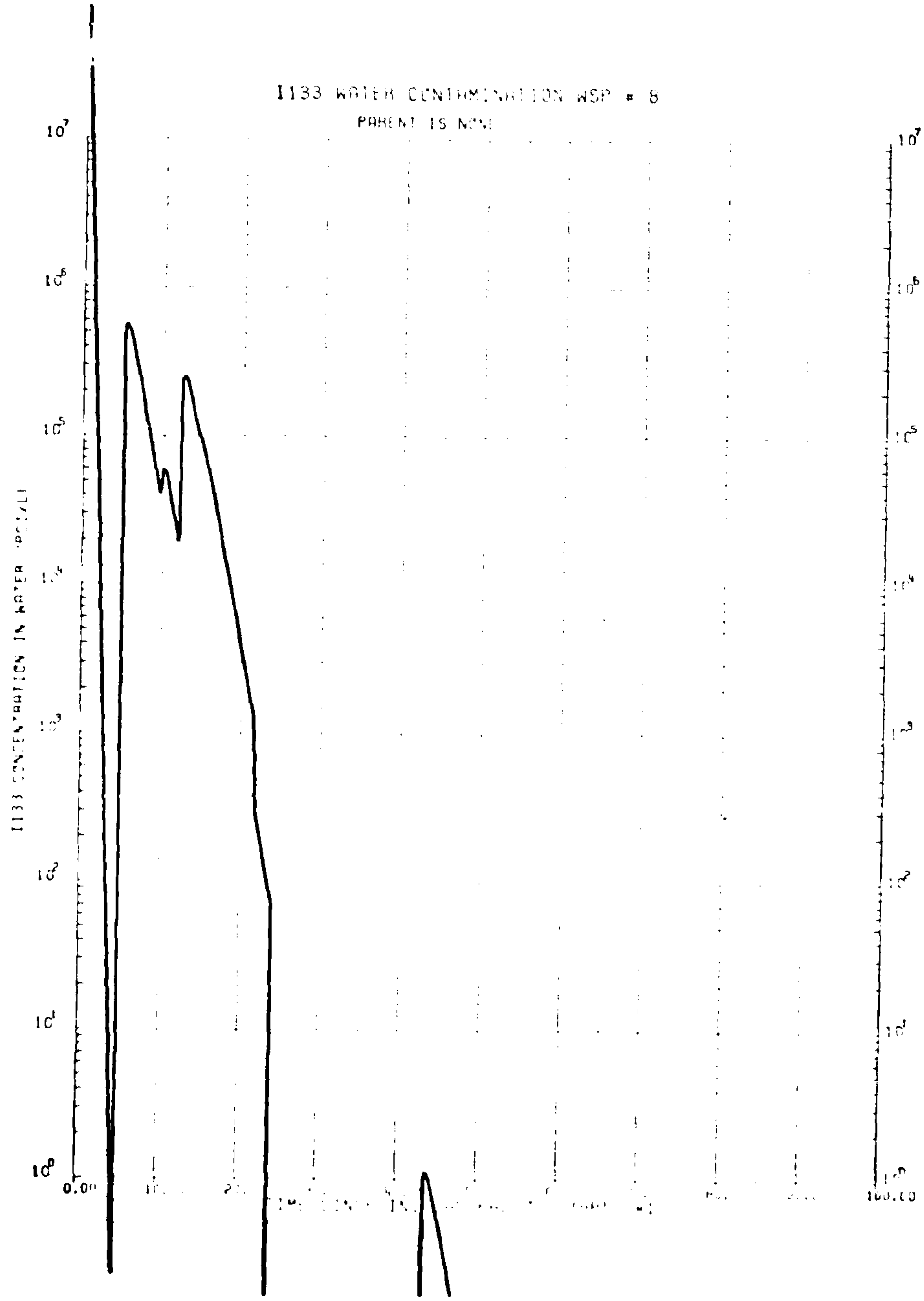


Figure B-14. I-133 water contamination.

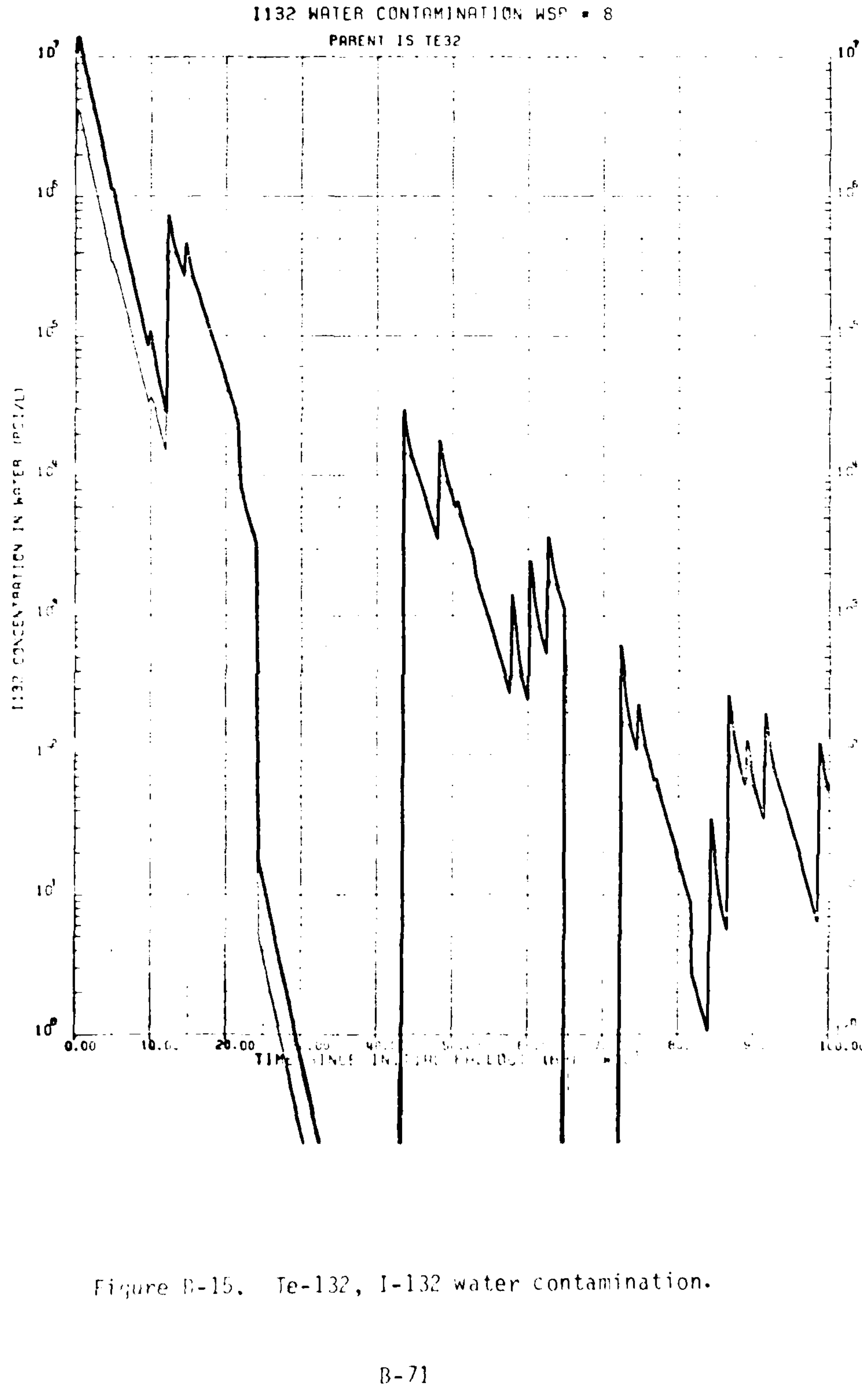


Figure B-15. Te-132, I-132 water contamination.

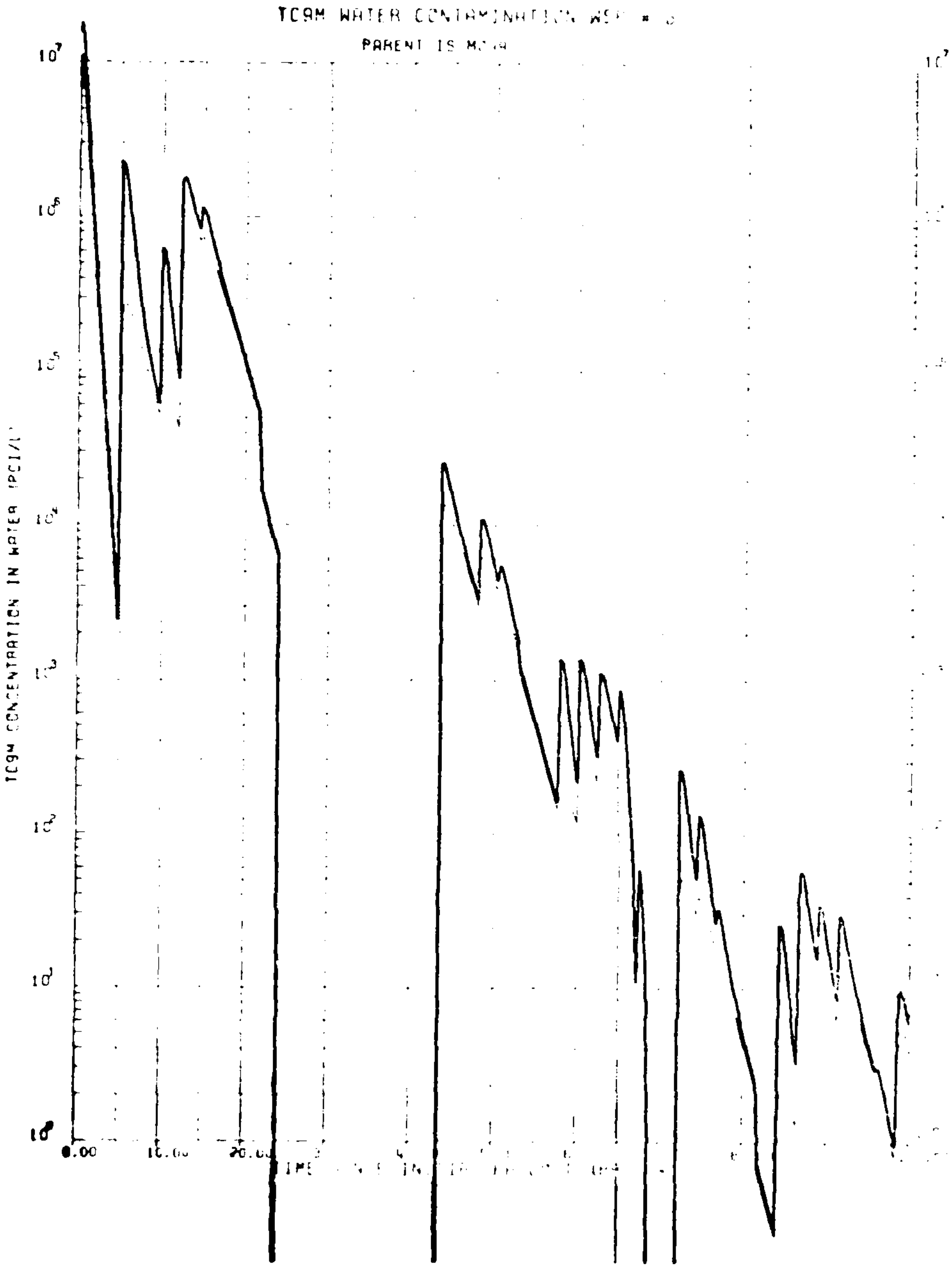


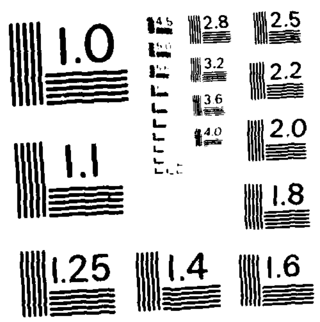
Figure 8-16. Mo-99, Tc-99m water contamination.

AD-A131 425 NUCLEAR WARFARE WATER CONTAMINATION(U) SCIENCE APPLICATIONS INC SCHAUMBURG IL J C PHILLIPS ET AL. 01 MAY 82 DNA-TR-81-127 DNA001-81-C-0234

3/3

UNCLASSIFIED F/G 15/6 NL

END
DATE
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

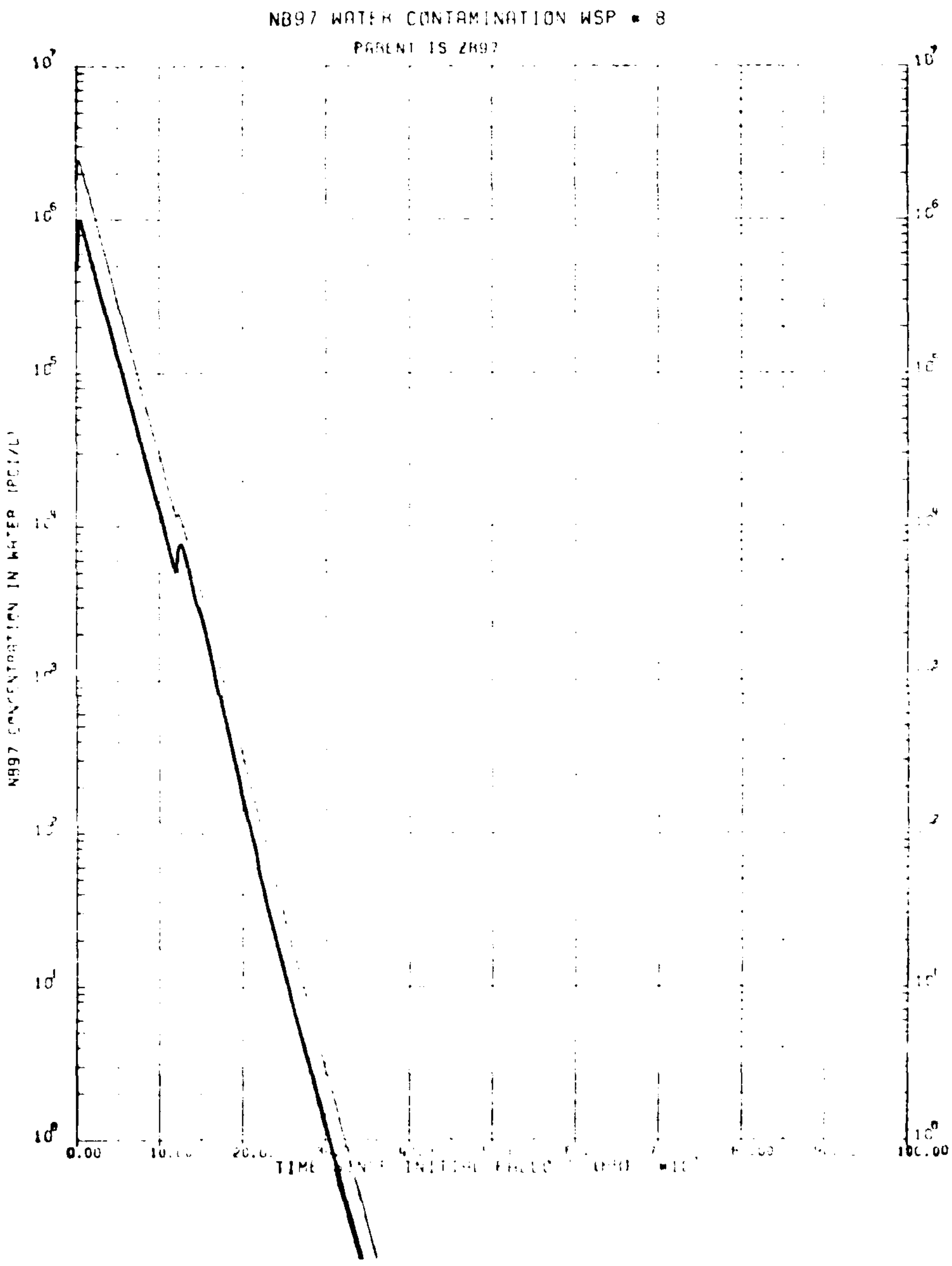


Figure B-17. Zr-97, Nb-97 water contamination.

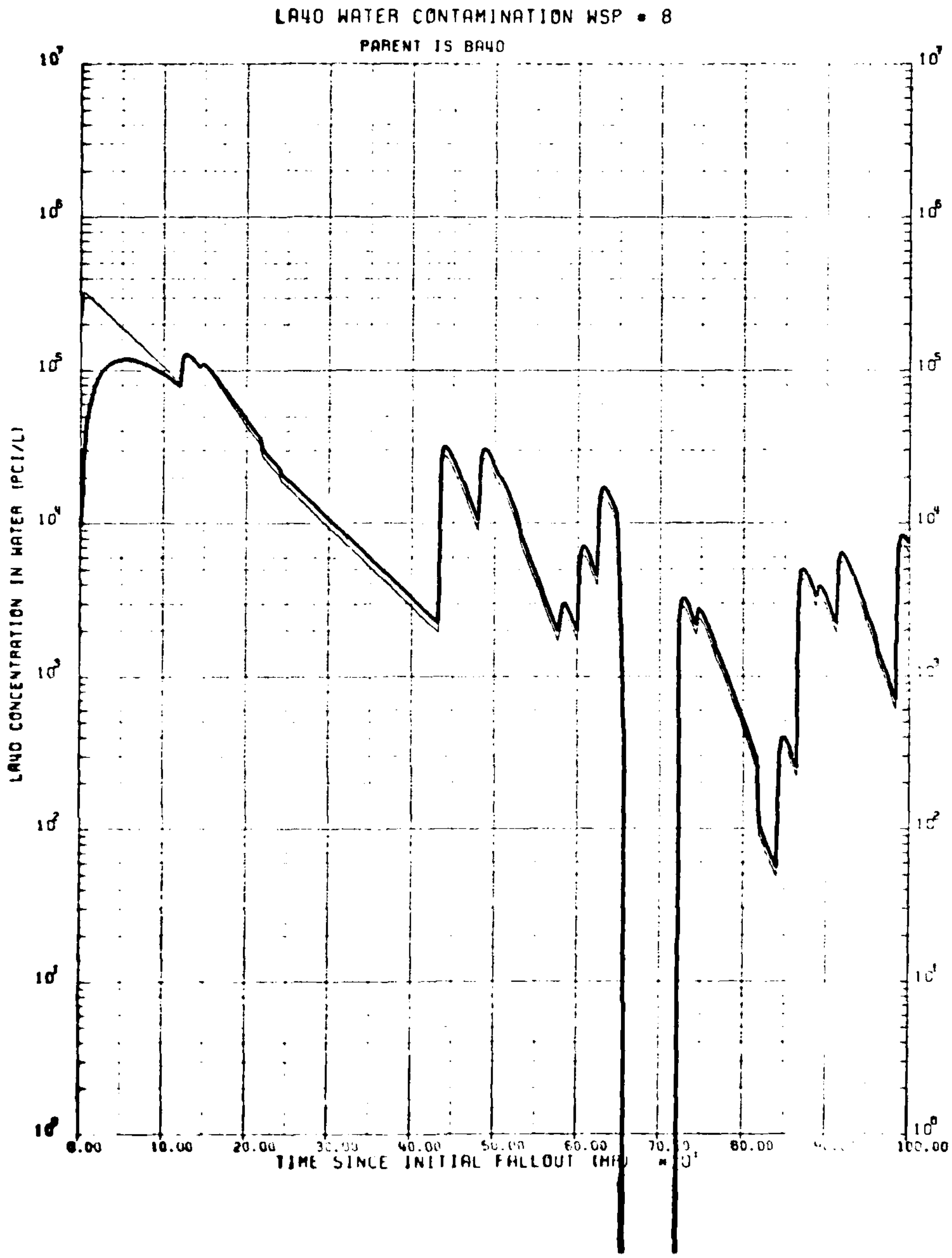


Figure B-18. Ba-140, La-140 water contamination.

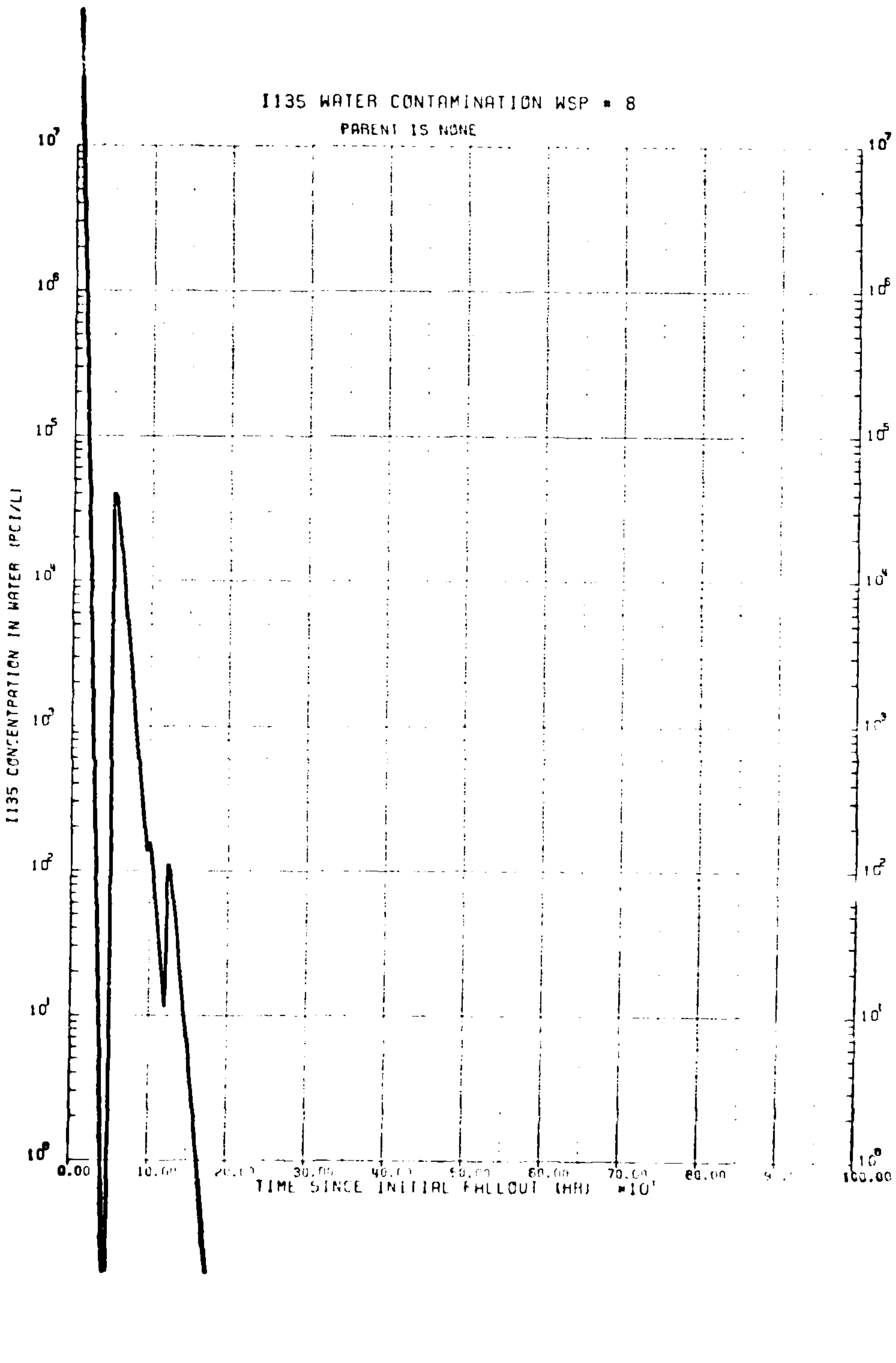


Figure B-19. I-135 water contamination.

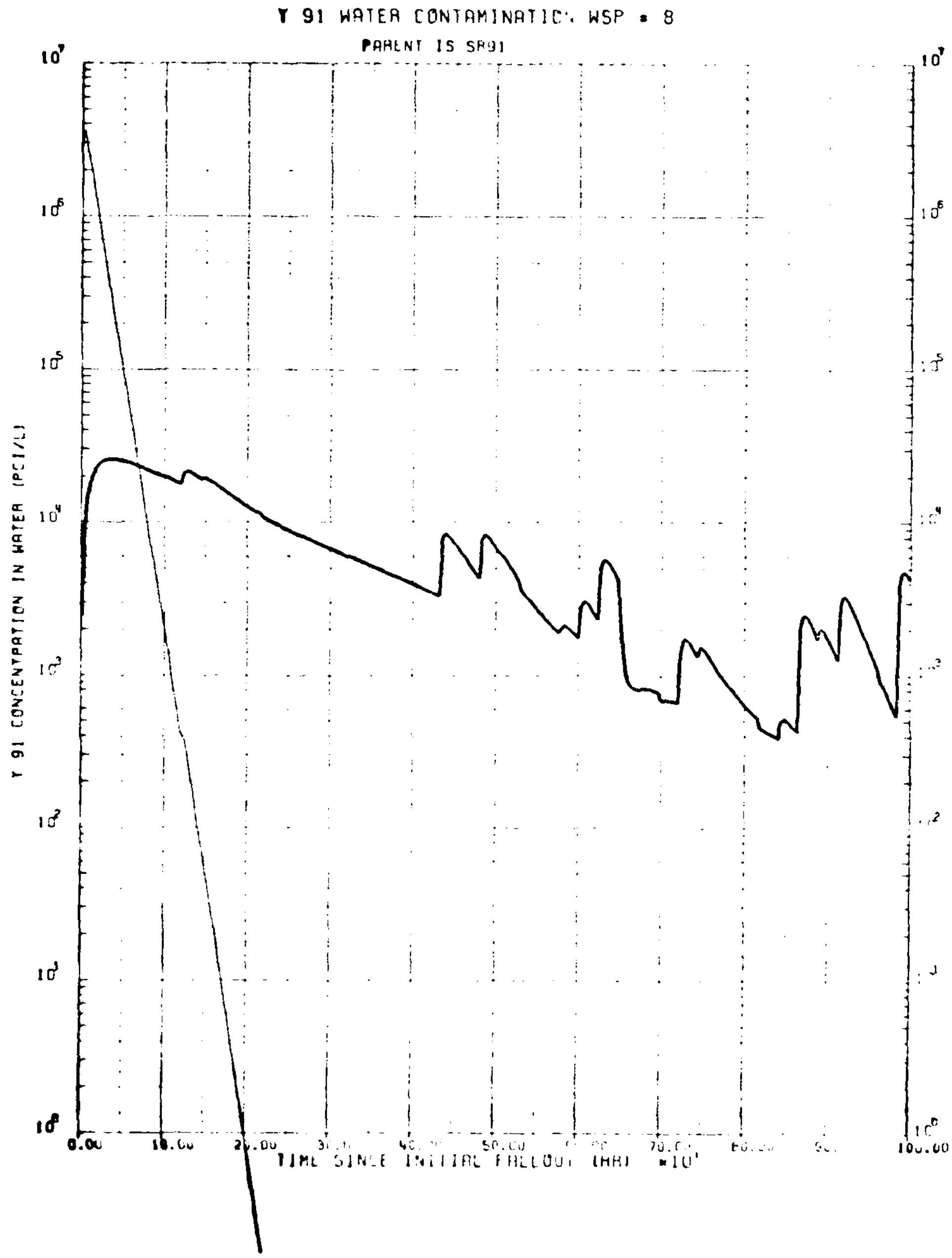


Figure B-20. Sr-91, Y-91 water contamination.

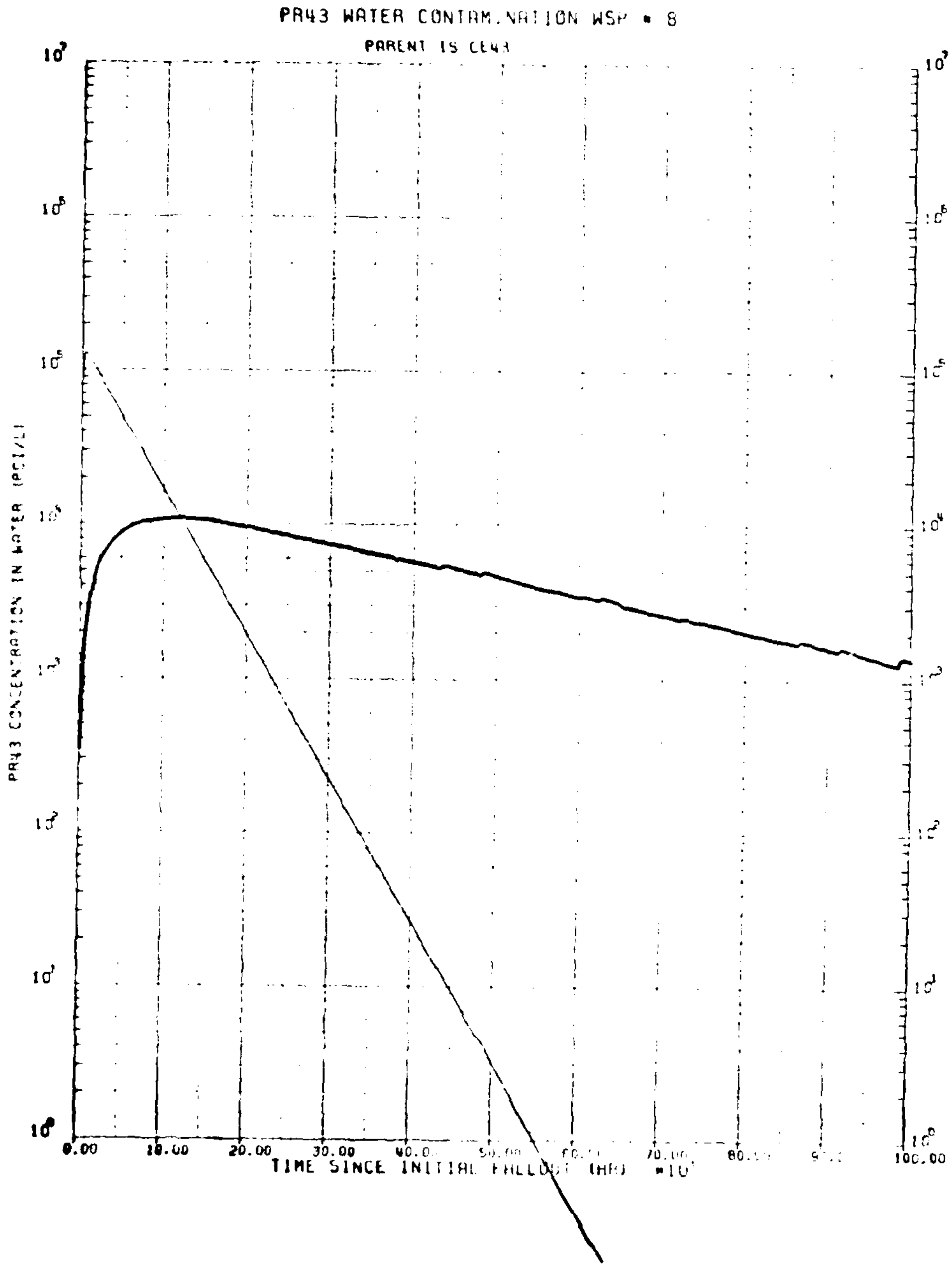


Figure B-21. Ce-143, Pr-143 water contamination.

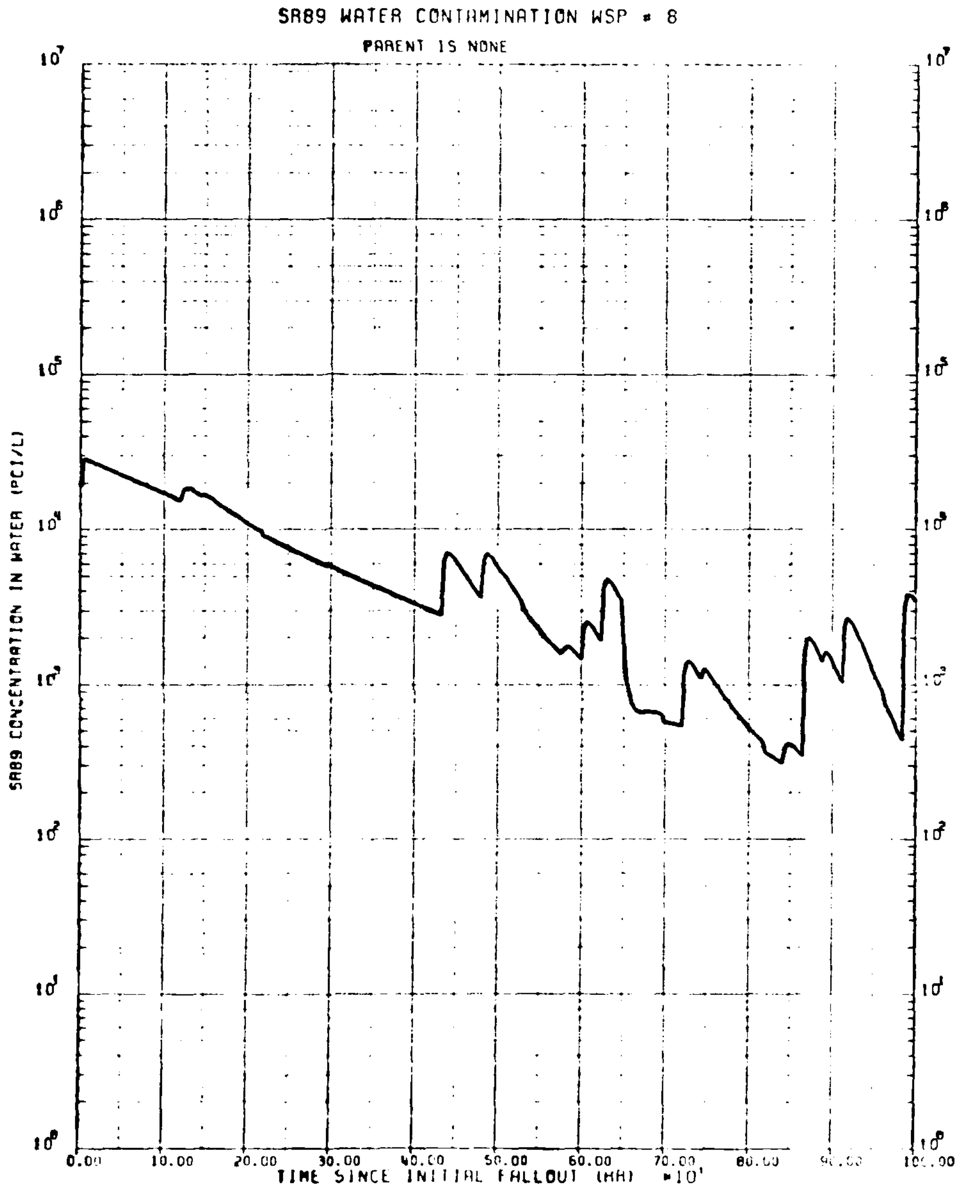


Figure B-22. Sr-89 water contamination.

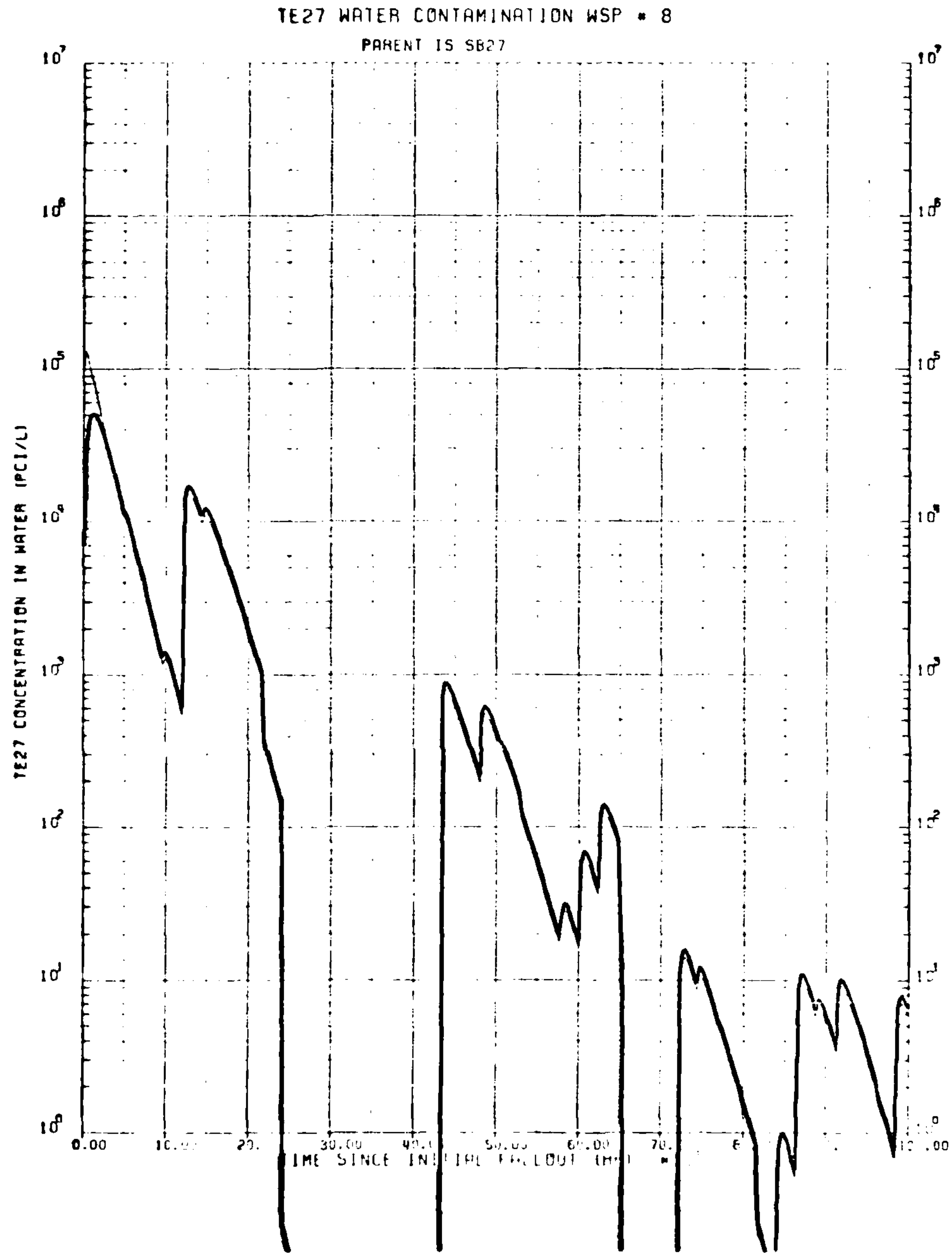


Figure B-23. Sb-127, Te-127 water contamination.

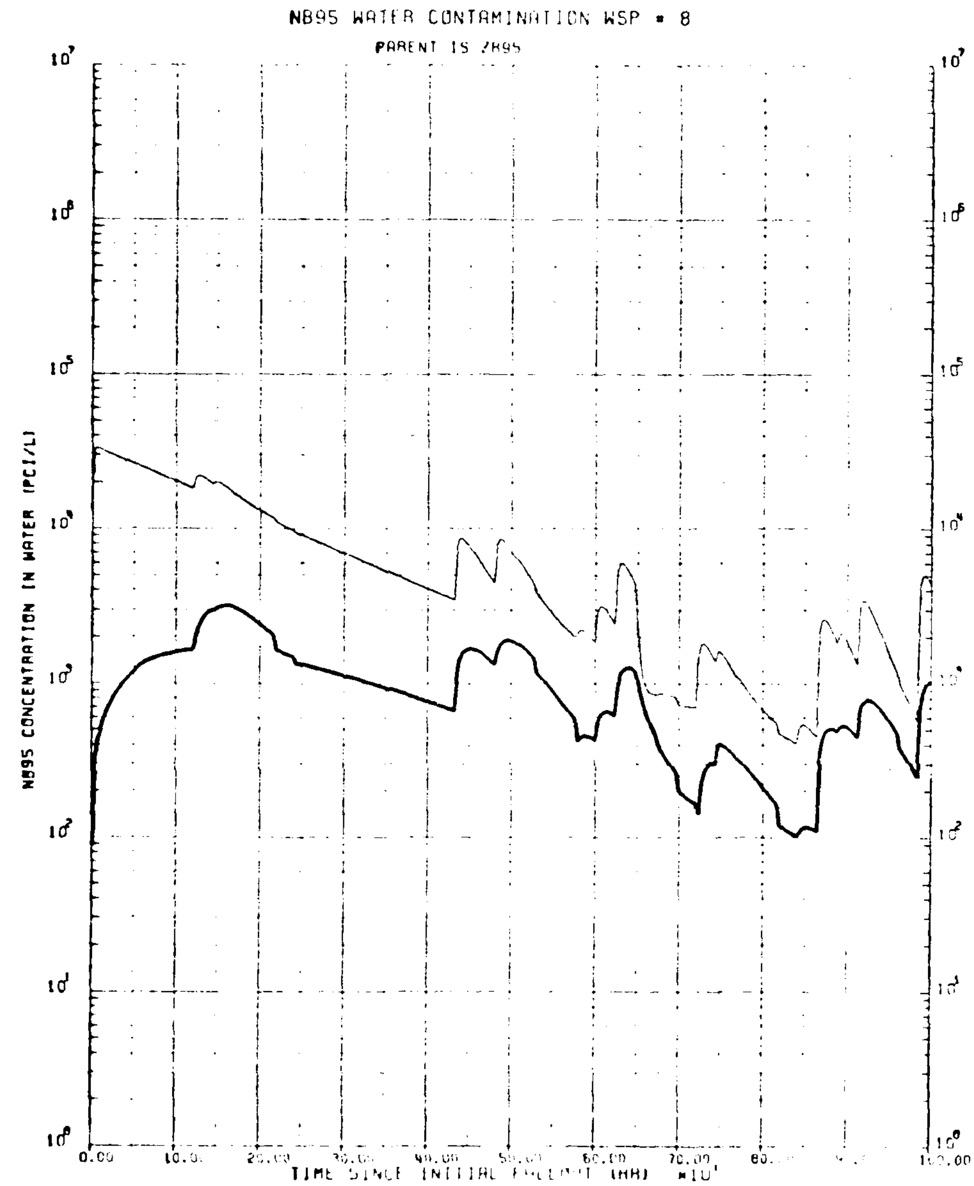


Figure B-24. Zr-95, Nb-95 water contamination.

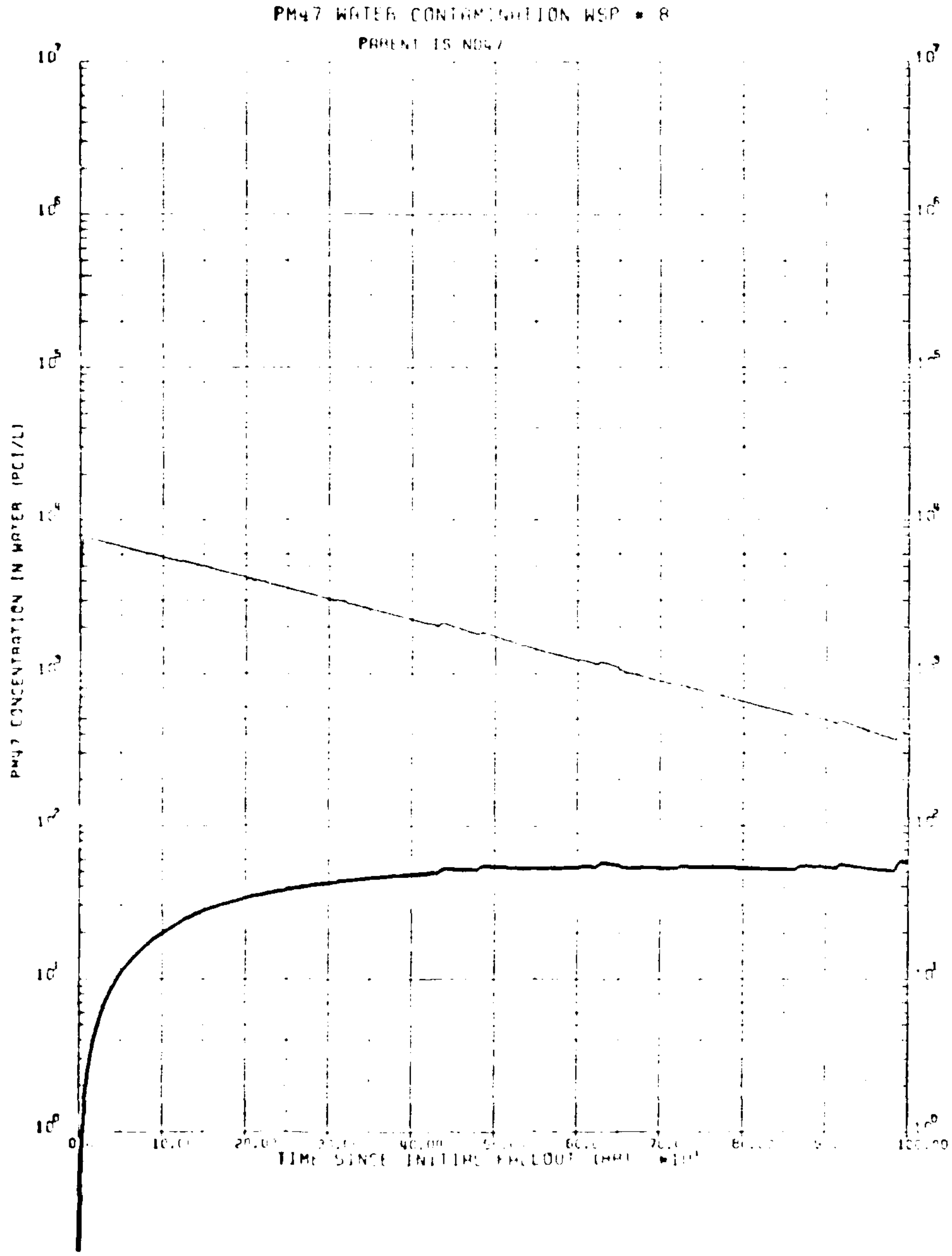


Figure B-25. Nd-147, Pm-147 water contamination.

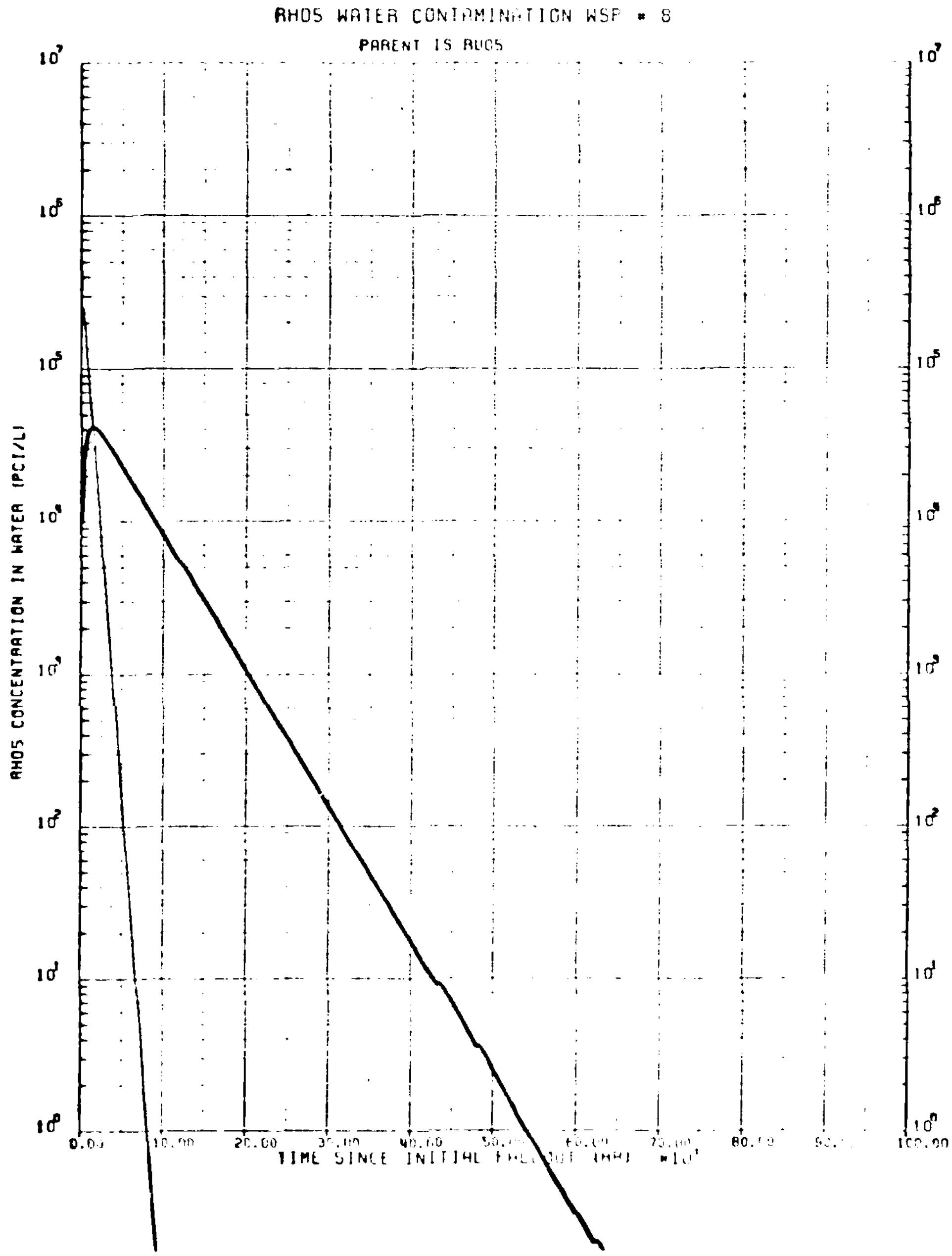


Figure B-26. Ru-105, Rh-105 water contamination.

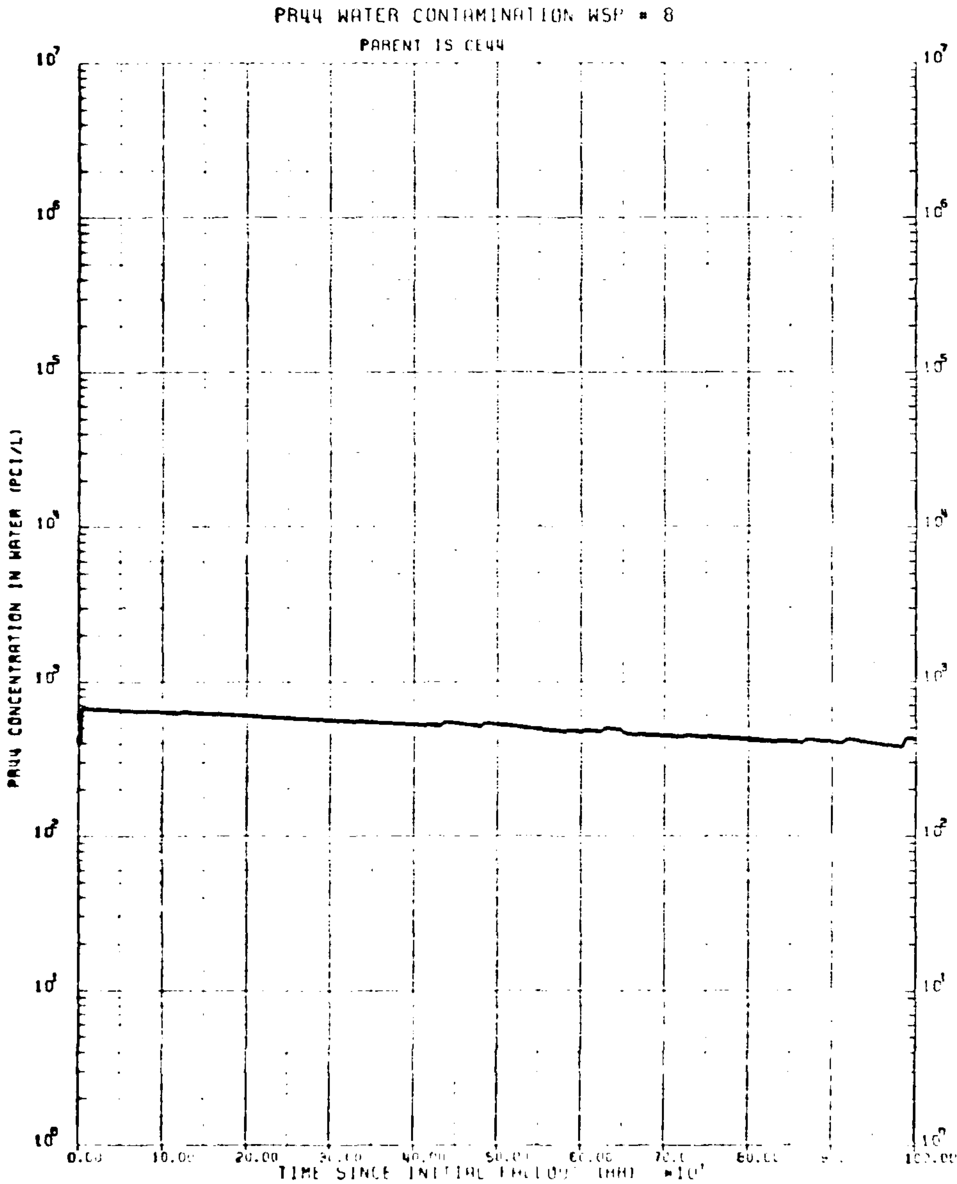


Figure B-27. Ce-144, Pr-144 water contamination.

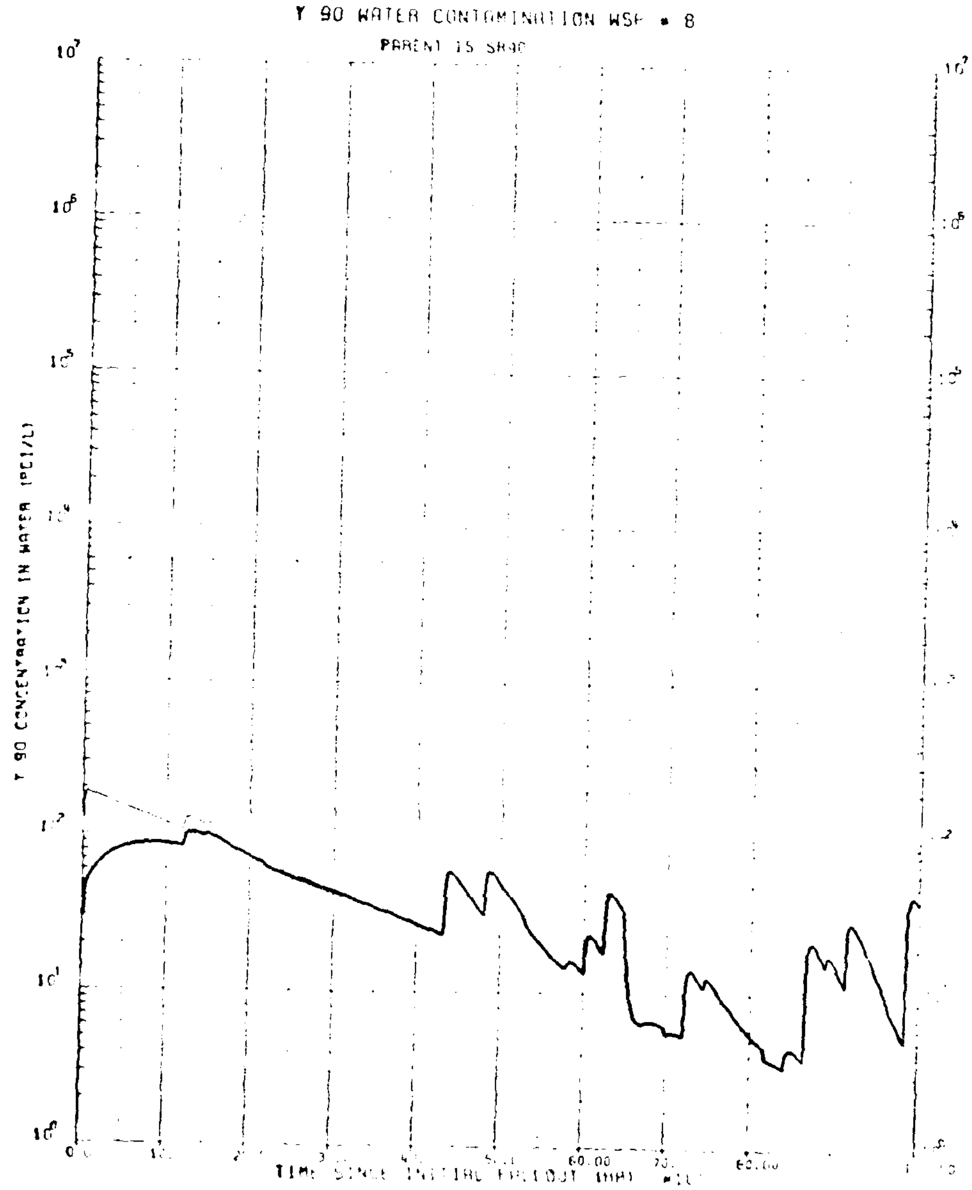


Figure B-28. Sr-90, Y-90 Water contamination.

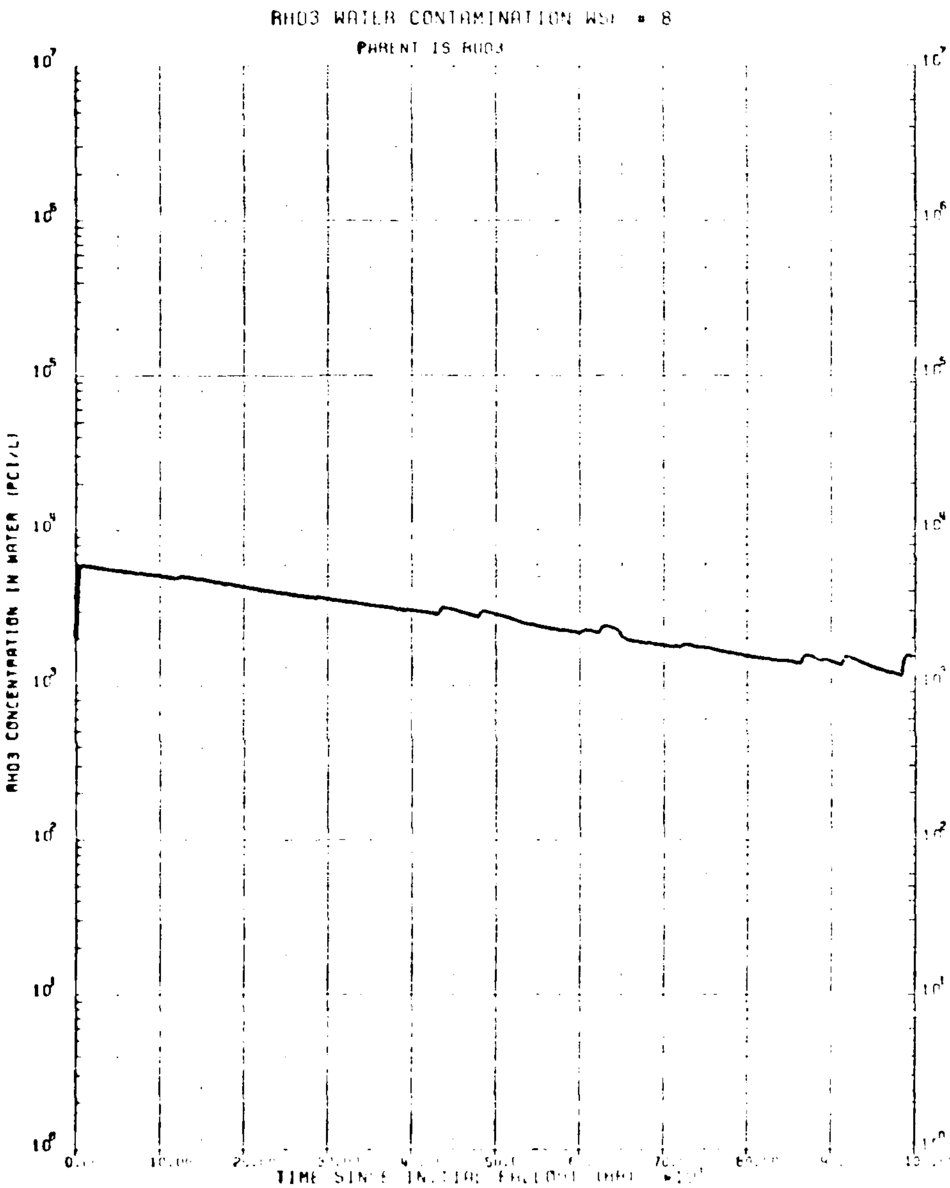


Figure B-29. Ru-103, Rh-103 water contamination.

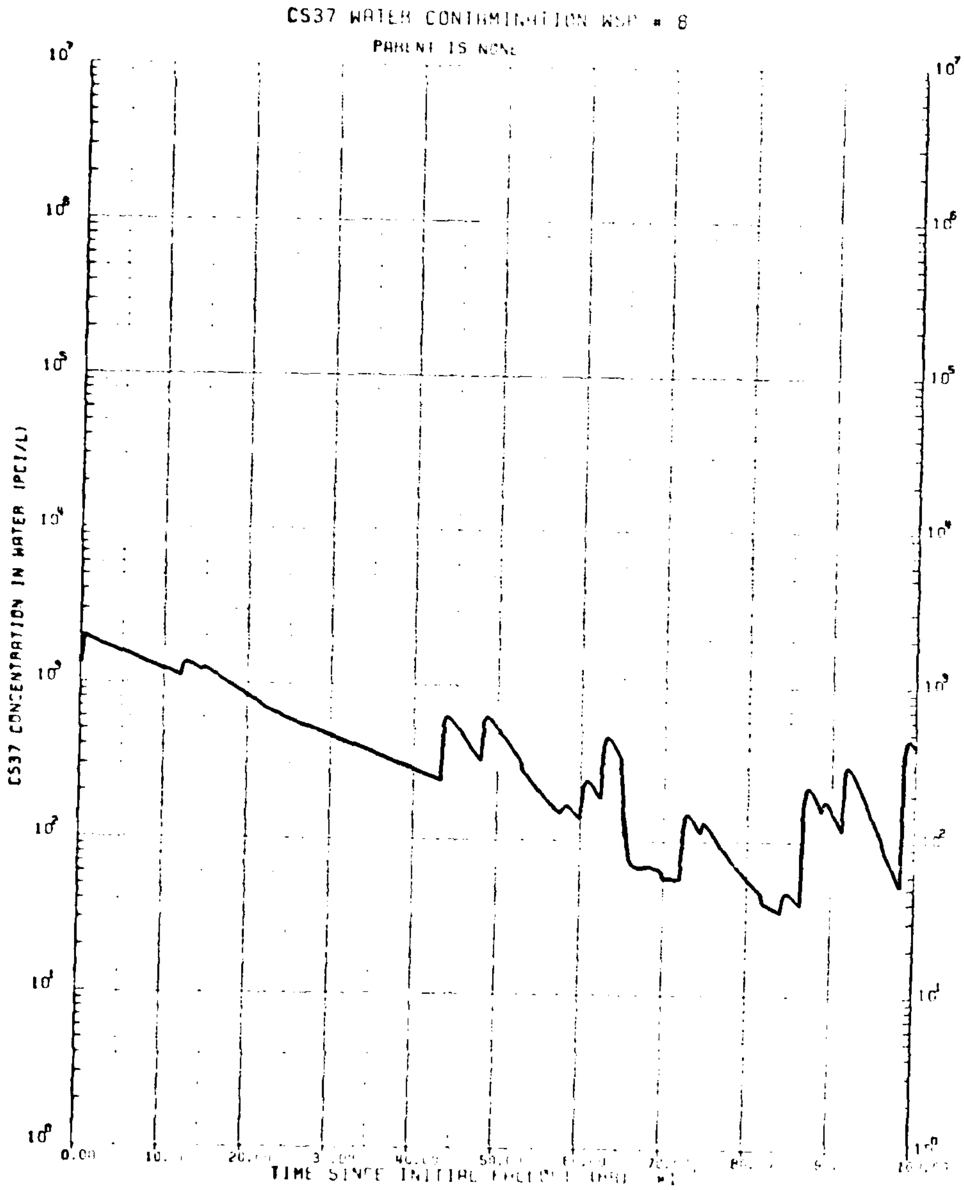


Figure B-30. Cs-137 water contamination.

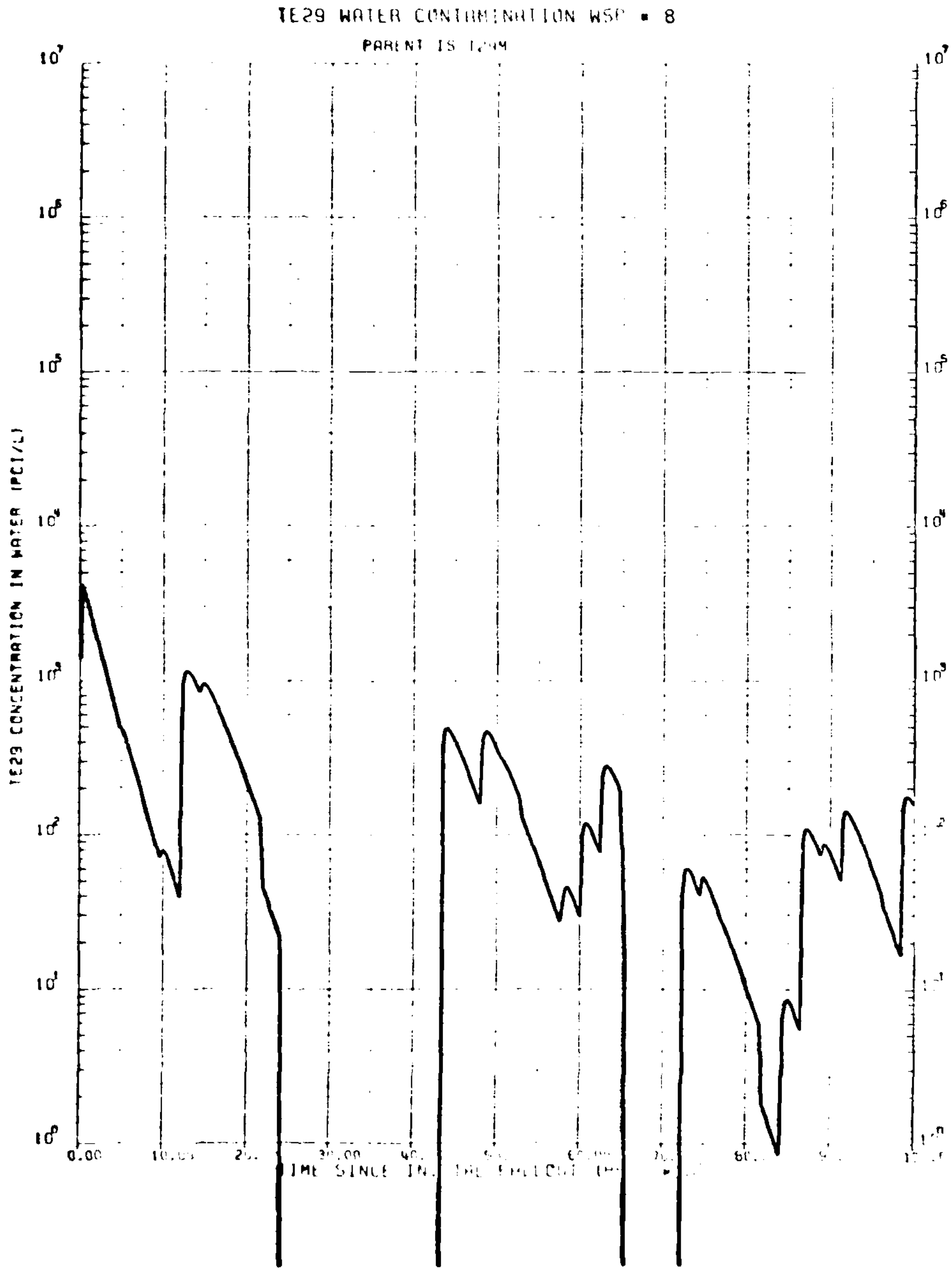


Figure B-31. Te-129m, Te-129 water contamination.

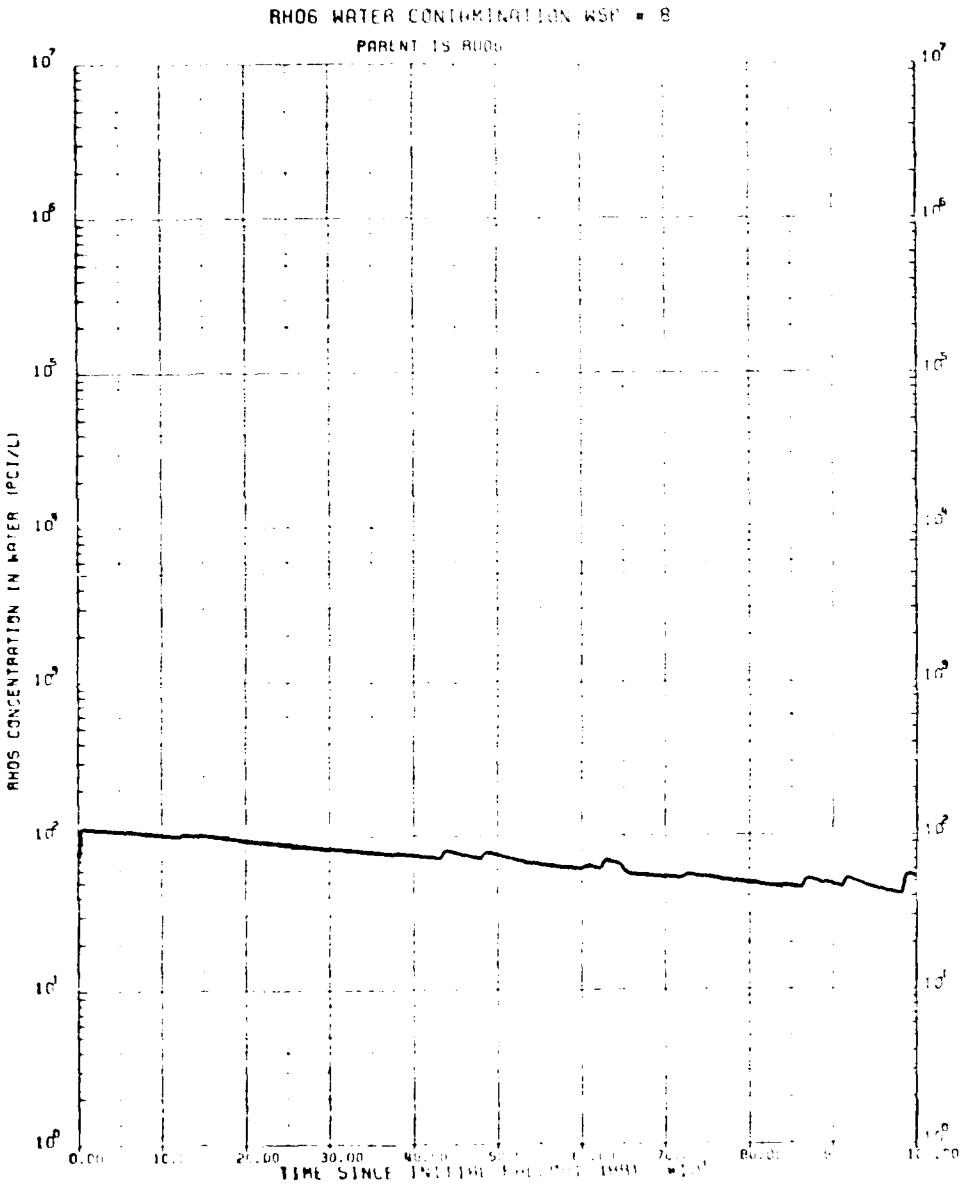


Figure B-32. Ru-106, Rh-106 water contamination.

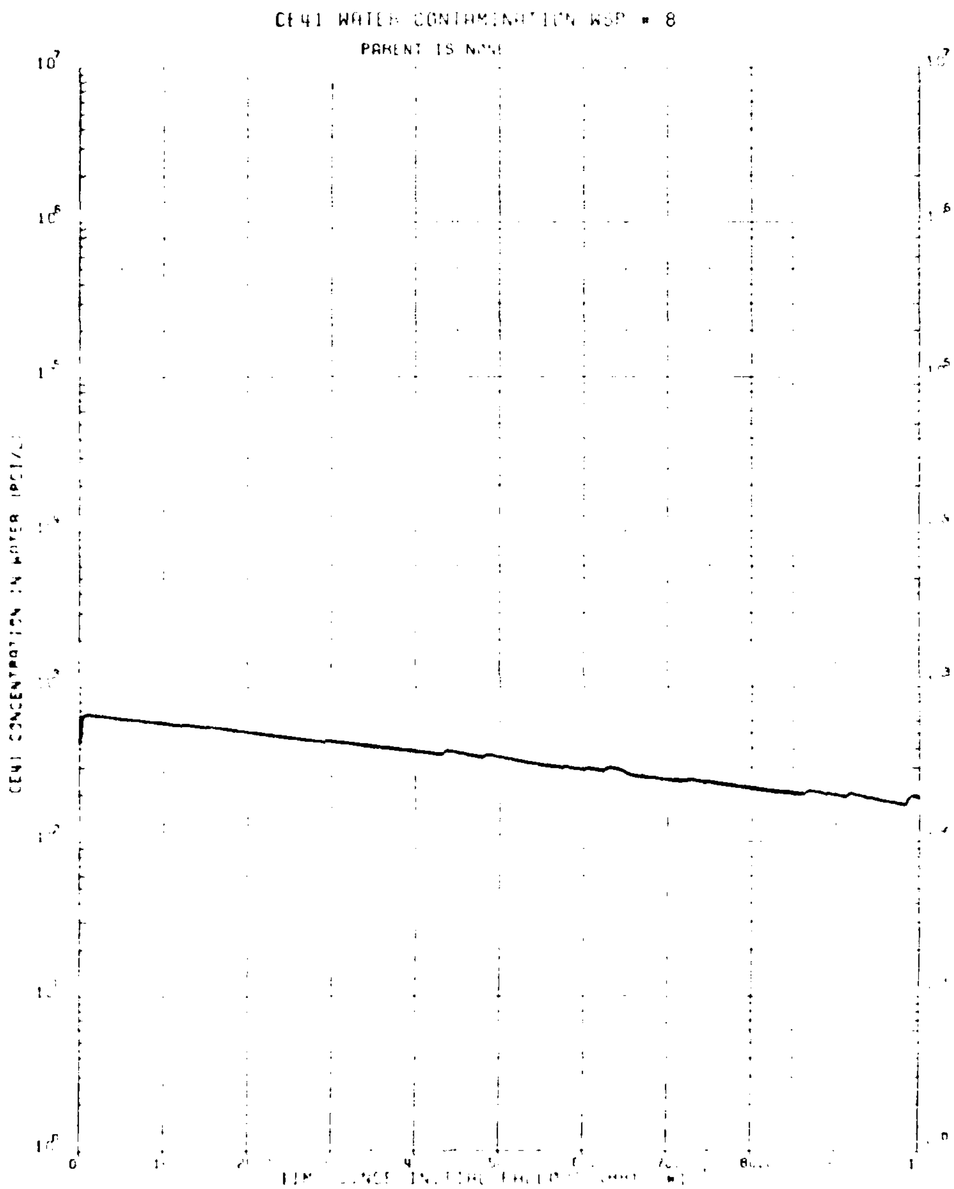


Figure B-33. Ce-141 water contamination.

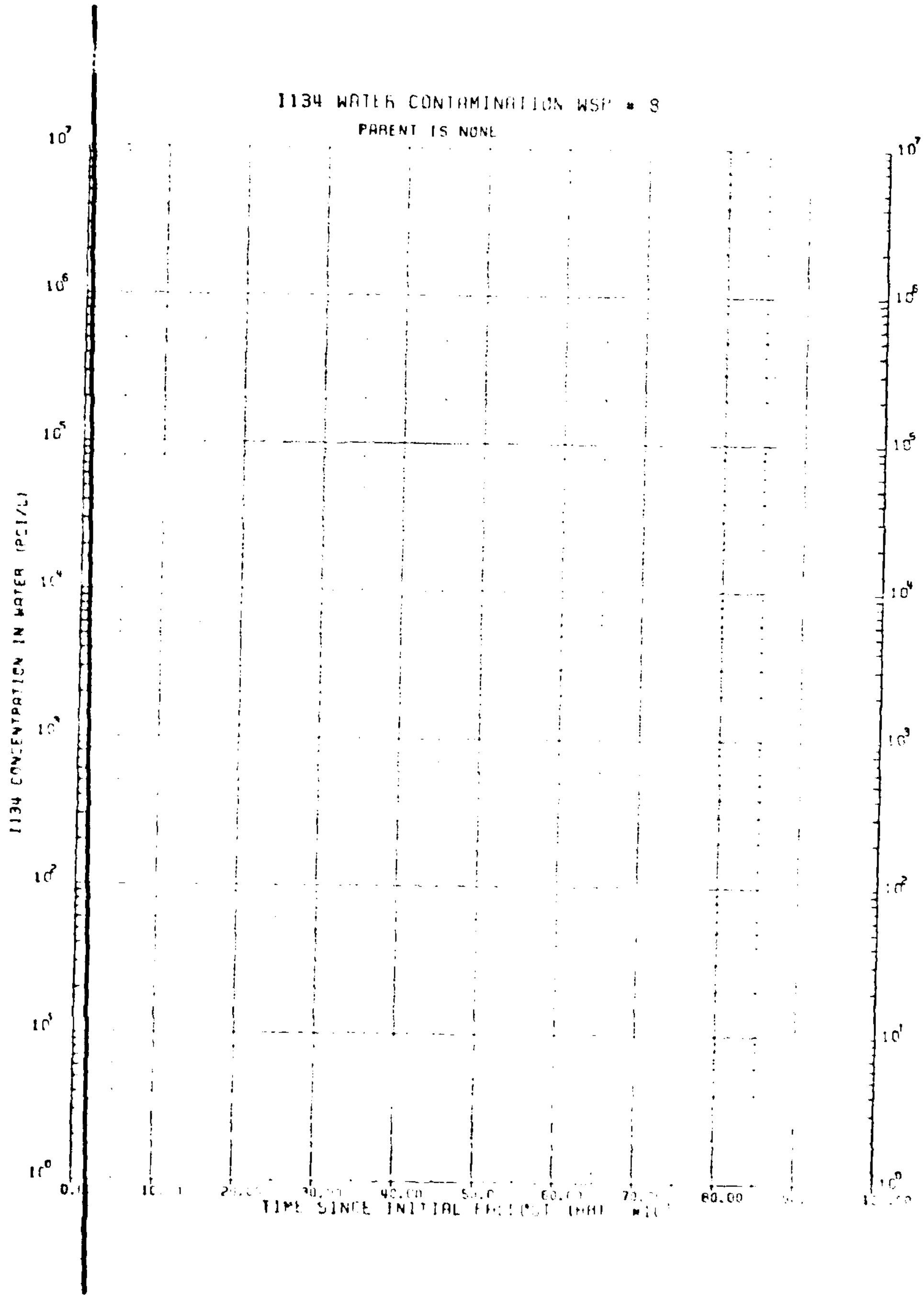


Figure B-34. I-134 water contamination.

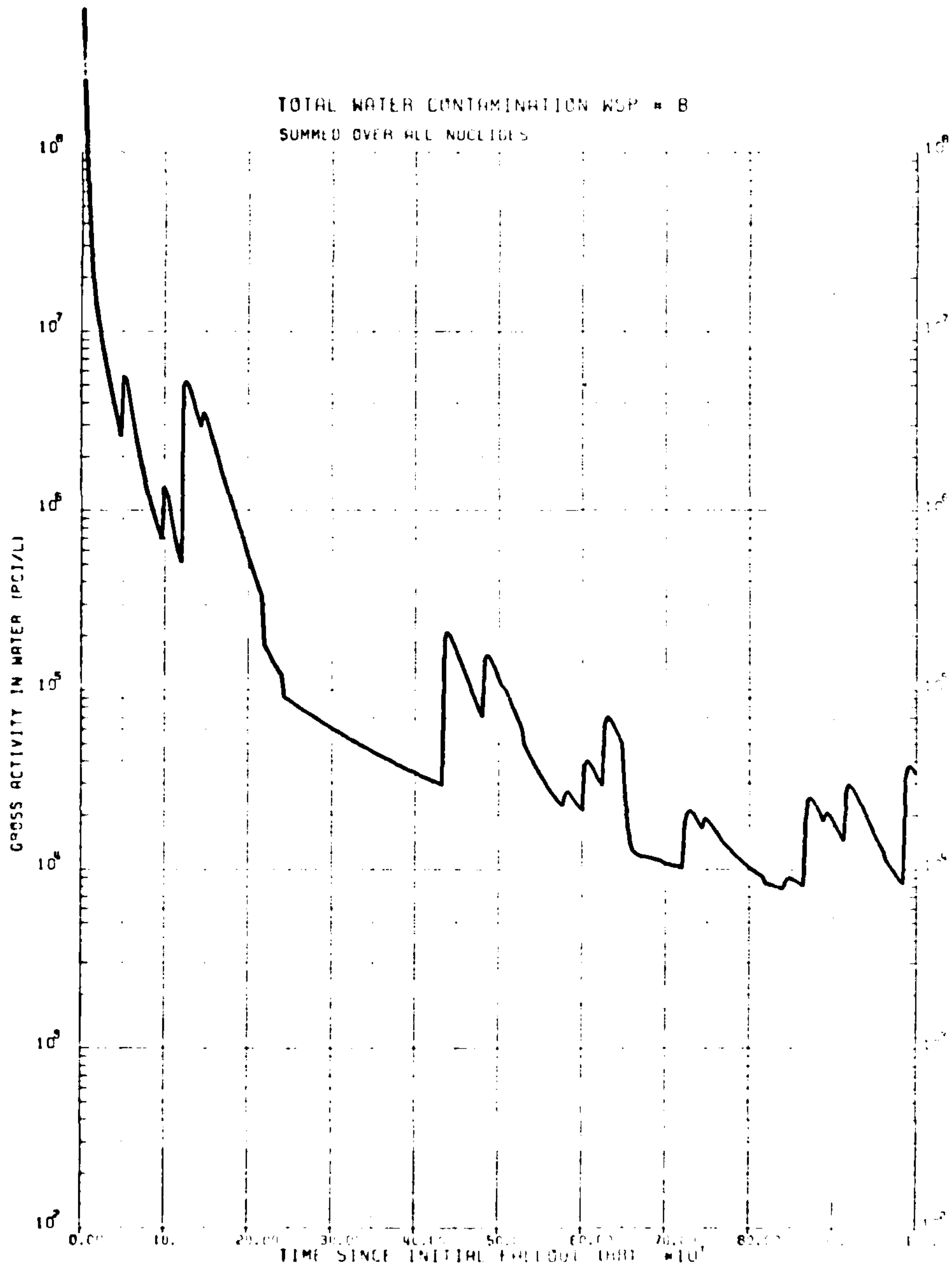


Figure B-35. Total water contamination.

Table B-13. Time-integrated radionuclide concentrations.
(pCi-Day/[illegible])

DAY	[illegible]	[illegible]
1	4.055E+05	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]

DAY	MO99	TC99M
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]

DAY	NONE	I135
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]

DAY	NONE	SR89
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]

DAY	NONE	[illegible]
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]

DAY	[illegible]	[illegible]
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]

DAY	[illegible]	[illegible]
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]

DAY	[illegible]	[illegible]
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]

Table B-13. Time-integrated radionuclide concentrations (cont).
(pCi-Day/ℓ)

DAY	TE32	I132
1	2.554E+05	8.402E+06
2	3.243E+06	1.080E+07
3	3.511E+06	1.143E+07
4	3.578E+06	1.167E+07
5	3.625E+06	[illegible]
6	3.942E+06	[illegible]
7	[illegible]	1.245E+07
8	[illegible]	1.255E+07
9	4.322E+06	1.253E+07
10	4.324E+06	1.262E+07
11	4.329E+06	1.262E+07
12	4.329E+06	1.262E+07
13	[illegible]	[illegible]
14	4.329E+06	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	4.362E+06	[illegible]
32	4.362E+06	1.264E+07
33	4.362E+06	1.264E+07
34	4.362E+06	[illegible]
35	4.362E+06	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	0.000E-01	0.000E-01

DAY	BA40	LA40
1	2.801E+05	5.843E+04
2	5.046E+05	1.674E+05
3	6.749E+05	[illegible]
4	8.025E+05	3.897E+05
5	8.935E+05	[illegible]
6	1.016E+06	5.953E+05
7	[illegible]	6.947E+05
8	1.175E+06	7.625E+05
9	1.216E+06	[illegible]
10	1.240E+06	8.344E+05
11	[illegible]	8.534E+05
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	9.012E+05
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	1.340E+06	9.942E+05
24	[illegible]	9.972E+05
25	1.345E+06	9.996E+05
26	1.390E+06	[illegible]
27	1.422E+06	1.020E+06
28	[illegible]	1.021E+06
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	0.000E-01	0.000E-01

DAY	CE43	PR43
1	1.238E+05	3.208E+03
2	1.724E+05	1.255E+04
3	2.103E+05	2.001E+04
4	2.340E+05	3.044E+04
5	2.482E+05	[illegible]
6	2.568E+05	5.193E+04
7	2.622E+05	[illegible]
8	[illegible]	[illegible]
9	2.669E+05	[illegible]
10	2.679E+05	[illegible]
11	2.686E+05	[illegible]
12	2.690E+05	[illegible]
13	[illegible]	[illegible]
14	2.693E+05	1.213E+05
15	2.694E+05	[illegible]
16	2.635E+05	1.342E+05
17	2.695E+05	[illegible]
18	2.695E+05	1.453E+05
19	2.695E+05	1.506E+05
20	2.695E+05	[illegible]
21	2.695E+05	1.603E+05
22	2.695E+05	[illegible]
23	2.695E+05	[illegible]
24	2.695E+05	[illegible]
25	2.695E+05	[illegible]
26	2.695E+05	[illegible]
27	2.695E+05	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	2.695E+05	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	2.695E+05	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	2.695E+05	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	0.000E-01	0.000E-01

DAY	ZR95	NB95
1	3.034E+04	5.059E+02
2	[illegible]	[illegible]
3	8.333E+04	2.812E+03
4	[illegible]	[illegible]
5	1.253E+05	5.965E+03
6	1.463E+05	[illegible]
7	[illegible]	[illegible]
8	[illegible]	1.450E+04
9	1.974E+05	1.682E+04
10	2.039E+05	1.842E+04
11	2.129E+05	1.974E+04
12	2.208E+05	2.095E+04
13	[illegible]	2.206E+04
14	2.339E+05	2.311E+04
15	2.392E+05	2.403E+04
16	2.440E+05	2.492E+04
17	[illegible]	2.568E+04
18	2.519E+05	2.636E+04
19	[illegible]	2.765E+04
20	[illegible]	2.935E+04
21	[illegible]	[illegible]
22	2.782E+05	3.283E+04
23	2.815E+05	3.383E+04
24	2.836E+05	3.454E+04
25	2.859E+05	[illegible]
26	[illegible]	3.561E+04
27	[illegible]	3.675E+04
28	[illegible]	3.747E+04
29	[illegible]	[illegible]
30	2.966E+05	[illegible]
31	2.984E+05	[illegible]
32	[illegible]	[illegible]
33	3.007E+05	[illegible]
34	3.013E+05	3.912E+04
35	3.016E+05	3.922E+04
36	[illegible]	[illegible]
37	3.045E+05	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	3.109E+05	[illegible]
41	[illegible]	[illegible]
42	0.000E-01	0.000E-01

DAY	ND47	PM47
1	7.123E+03	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	2.674E+04	[illegible]
5	3.235E+04	[illegible]
6	[illegible]	[illegible]
7	4.255E+04	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	5.876E+04	[illegible]
12	6.229E+04	[illegible]
13	[illegible]	[illegible]
14	6.874E+04	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	9.54?E+02
27	9.141E+04	[illegible]
28	9.242E+04	1.104E+03
29	9.316E+04	1.154E+03
30	[illegible]	1.211E+03
31	9.504E+04	1.265E+03
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	9.842E+04	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	1.022E+05	[illegible]
41	1.026E+05	[illegible]
42	0.000E-01	0.000E-01

DAY	SR90	Y90
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	1.334E+03
25	[illegible]	1.349E+03
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	1.845E+03	[illegible]
32	1.856E+03	1.454E+03
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	1.894E+03	[illegible]
38	[illegible]	[illegible]
39	1.914E+03	[illegible]
40	[illegible]	[illegible]
41	[illegible]	1.554E+03
42	0.000E-01	0.000E-01

DAY	TC99M	TE29
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]
11	[illegible]	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	8.949E+03	8.812E+03
41	[illegible]	[illegible]
42	0.000E-01	0.000E-01

DAY	NONE	I134
1	0.000E-01	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	0.000E-01	[illegible]
11	0.000E-01	[illegible]
12	[illegible]	[illegible]
13	[illegible]	[illegible]
14	[illegible]	[illegible]
15	[illegible]	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	[illegible]
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	[illegible]
24	[illegible]	[illegible]
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	[illegible]
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	[illegible]
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	0.000E-01	[illegible]

Table B-13. Time-integrated radionuclide concentrations (cont).
(pCi-Day/[illegible])

DAY	RU05	RH05
1	8.104E+04	3.493E+04
2	8.339E+04	6.516E+04
3	8.345E+04	8.388E+04
4	8.345E+04	9.532E+04
5	8.345E+04	1.025E+05
6	8.345E+04	1.067E+05
7	8.345E+04	1.094E+05
8	8.345E+04	1.111E+05
9	8.345E+04	1.121E+05
10	8.345E+04	1.127E+05
11	8.345E+04	1.130E+05
12	8.345E+04	1.133E+05
13	8.345E+04	1.134E+05
14	8.345E+04	1.135E+05
15	8.345E+04	1.13[illegible]E+05
16	8.345E+04	1.13[illegible]E+05
17	8.345E+04	1.13[illegible]E+05
18	8.345E+04	1.13[illegible]E+05
19	8.345E+04	1.136E+05
20	8.345E+04	1.136E+05
21	8.345E+04	1.13[illegible]E+05
22	8.345E+04	1.136E+05
23	8.345E+04	1.13[illegible]E+05
24	8.345E+04	1.136E+05
25	8.345E+04	1.136E+05
26	8.345E+04	1.13[illegible]E+05
27	8.345E+04	1.136E+05
28	8.345E+04	1.136E+05
29	8.345E+04	1.13[illegible]E+05
30	8.345E+04	1.136E+05
31	8.345E+04	1.136E+05
32	8.345E+04	1.136E+05
33	8.345E+04	1.136E+05
34	8.345E+04	1.13[illegible]E+05
35	8.345E+04	1.13[illegible]E+05
36	8.345E+04	1.13[illegible]E+05
37	8.345E+04	1.13[illegible]E+05
38	8.345E+04	1.13[illegible]E+05
39	8.345E+04	1.136E+05
40	8.345E+04	1.13[illegible]E+05
41	8.345E+04	1.13[illegible]E+05
42	0.000E-01	0.000E-01

DAY	RU03	RH03
1	5.546E+03	5.412E+03
2	1.119E+04	1.120E+04
3	1.651E+04	1.649E+04
4	2.182E+04	2.172E+04
5	2.681E+04	2.670E+04
6	3.177E+04	3.167E+04
7	3.655E+04	3.643E+04
8	4.107E+04	4.09[illegible]E+04
9	4.536E+04	4.52[illegible]E+04
10	4.944E+04	4.93[illegible]E+04
11	5.334E+04	5.325E+04
12	5.708E+04	5.70[illegible]E+04
13	6.068E+04	6.060E+04
14	6.413E+04	6.405E+04
15	6.744E+04	6.7[illegible]E+04
16	7.062E+04	7.05[illegible]E+04
17	7.367E+04	7.360E+04
18	7.6[illegible]E+04	7.65[illegible]E+04
19	7.953E+04	7.94[illegible]E+04
20	8.256E+04	8.25[illegible]E+04
21	8.549E+04	8.54[illegible]E+04
22	8.813E+04	8.81[illegible]E+04
23	9.067E+04	9.0[illegible]E+04
24	9.300E+04	9.29[illegible]E+04
25	9.524E+04	9.51[illegible]E+04
26	9.746E+04	9.74[illegible]E+04
27	9.978E+04	9.974E+04
28	1.017E+05	1.017E+05
29	1.036E+05	1.03[illegible]E+05
30	1.054E+05	1.054E+05
31	1.072E+05	1.071E+05
32	1.089E+05	1.089E+05
33	1.105E+05	1.105E+05
34	1.120E+05	1.120E+05
35	1.135E+05	1.135E+05
36	1.149E+05	1.149E+05
37	1.164E+05	1.164E+05
38	1.17[illegible]E+05	1.17[illegible]E+05
39	1.1[illegible]E+05	1.193E+05
40	1.206E+05	1.206E+05
41	1.2[illegible]E+05	1.219E+05
42	0.000E-01	0.000E-01

DAY	RU06	RH06
1	1.052E+02	1.052E+02
2	2.139E+02	2.139E+02
3	3.200E+02	3.200E+02
4	4.234E+02	4.234E+02
5	5.242E+02	5.242E+02
6	6.260E+02	6.260E+02
7	7.254E+02	7.254E+02
8	8.213E+02	8.213E+02
9	9.133E+02	9.133E+02
10	1.002E+03	1.002E+03
11	1.089E+03	1.087E+03
12	1.173E+03	1.172E+03
13	1.256E+03	1.256E+03
14	1.336E+03	1.335E+03
15	1.414E+03	1.417E+03
16	1.490E+03	1.49[illegible]E+03
17	1.565E+03	1.56[illegible]E+03
18	1.637E+03	1.63[illegible]E+03
19	1.7[illegible]E+03	1.71[illegible]E+03
20	1.7[illegible]E+03	1.7[illegible]E+03
21	1.8[illegible]E+03	1.864E+03
22	1.9[illegible]E+03	1.9[illegible]E+03
23	2.007E+03	2.00[illegible]E+03
24	2.0[illegible]E+03	2.06[illegible]E+03
25	2.1[illegible]E+03	2.127E+03
26	2.1[illegible]E+03	2.18[illegible]E+03
27	2.2[illegible]E+03	2.2[illegible]E+03
28	2.31[illegible]E+03	2.31[illegible]E+03
29	2.3[illegible]E+03	2.367E+03
30	2.4[illegible]E+03	2.42[illegible]E+03
31	2.4[illegible]E+03	2.475E+03
32	2.5[illegible]E+03	2.5[illegible]E+03
33	2.578E+03	2.578E+03
34	2.627E+03	2.627E+03
35	2.674E+03	2.674E+03
36	2.721E+03	2.721E+03
37	2.771E+03	2.771E+03
38	2.819E+03	2.81[illegible]E+03
39	2.869E+03	2.869E+03
40	2.916E+03	2.91[illegible]E+03
41	2.9[illegible]E+03	2.95[illegible]E+03
42	0.000E-01	0.000E-01

DAY	CE44	PR44
1	6.292E+02	6.292E+02
2	1.247E+03	1.2[illegible]E+03
3	1.935E+03	1.934E+03
4	2.575E+03	2.57[illegible]E+03
5	3.205E+03	3.204E+03
6	3.837E+03	3.836E+03
7	4.451E+03	4.4[illegible]E+03
8	5.072E+03	5.0[illegible]E+03
9	5.6[illegible]E+03	5.670E+03
10	6.259E+03	6.258E+03
11	6.835E+03	6.837E+03
12	7.404E+03	7.40[illegible]E+03
13	7.97[illegible]E+03	7.970E+03
14	8.526E+03	8.52[illegible]E+03
15	9.07[illegible]E+03	9.07[illegible]E+03
16	9.61[illegible]E+03	9.61[illegible]E+03
17	1.013E+04	1.01[illegible]E+04
18	1.067E+04	1.067E+04
19	1.1[illegible]E+04	1.121E+04
20	1.17[illegible]E+04	1.177E+04
21	1.22[illegible]E+04	1.22[illegible]E+04
22	1.27[illegible]E+04	1.27[illegible]E+04
23	1.32[illegible]E+04	1.32[illegible]E+04
24	1.37[illegible]E+04	1.37[illegible]E+04
25	1.42[illegible]E+04	1.42[illegible]E+04
26	1.47[illegible]E+04	1.47[illegible]E+04
27	1.521E+04	1.521E+04
28	1.567E+04	1.567E+04
29	1.611E+04	1.611E+04
30	1.656E+04	1.65[illegible]E+04
31	1.700E+04	1.700E+04
32	1.744E+04	1.743E+04
33	1.786E+04	1.78[illegible]E+04
34	1.828E+04	1.828E+04
35	1.869E+04	1.869E+04
36	1.912E+04	1.91[illegible]E+04
37	1.952E+04	1.95[illegible]E+04
38	1.993E+04	1.993E+04
39	2.035E+04	2.035E+04
40	2.075E+04	2.075E+04
41	2.114E+04	2.11[illegible]E+04
42	0.000E-01	0.000E-01

DAY	NONE	CS37
1	0.000E-01	1.78[illegible]E+03
2	0.000E-01	3.4[illegible]E+03
3	0.000E-01	4.9[illegible]E+03
4	0.000E-01	6.[illegible]E+03
5	0.000E-01	7.494E+03
6	0.000E-01	8.7[illegible]E+03
7	0.000E-01	9.9[illegible]E+03
8	0.000E-01	1.0[illegible]E+04
9	0.000E-01	1.1[illegible]E+04
10	0.000E-01	1.244E+04
11	0.000E-01	1.30[illegible]E+04
12	0.000E-01	1.358E+04
13	0.000E-01	1.40[illegible]E+04
14	0.000E-01	1.44[illegible]E+04
15	0.000E-01	1.480E+04
16	0.000E-01	1.51[illegible]E+04
17	0.000E-01	1.54[illegible]E+04
18	0.000E-01	1.567E+04
19	0.000E-01	1.6[illegible]E+04
20	0.000E-01	1.66[illegible]E+04
21	0.000E-01	1.71[illegible]E+04
22	0.000E-01	1.75[illegible]E+04
23	0.000E-01	1.78[illegible]E+04
24	0.000E-01	1.79[illegible]E+04
25	0.000E-01	1.81[illegible]E+04
26	0.000E-01	1.83[illegible]E+04
27	0.000E-01	1.8[illegible]E+04
28	0.000E-01	1.88[illegible]E+04
29	0.000E-01	1.894E+04
30	0.000E-01	1.900E+04
31	0.000E-01	1.91[illegible]E+04
32	0.000E-01	1.921E+04
33	0.000E-01	1.93[illegible]E+04
34	0.000E-01	1.93[illegible]E+04
35	0.000E-01	1.94[illegible]E+04
36	0.000E-01	1.94[illegible]E+04
37	0.000E-01	1.964E+04
38	0.000E-01	1.980E+04
39	0.000E-01	2.006E+04
40	0.000E-01	2.021E+04
41	0.000E-01	2.028E+04
42	0.000E-01	0.000E-01

DAY	NONE	CE41
1	0.000E-01	6.164E+02
2	0.000E-01	1.2[illegible]E+03
3	0.000E-01	1.86[illegible]E+03
4	0.000E-01	2.45[illegible]E+03
5	0.000E-01	3.0[illegible]E+03
6	0.000E-01	3.58[illegible]E+03
7	0.000E-01	4.1[illegible]E+03
8	0.000E-01	4.660E+03
9	0.000E-01	5.16[illegible]E+03
10	0.000E-01	5.65[illegible]E+03
11	0.000E-01	6.1[illegible]E+03
12	0.000E-01	6.57[illegible]E+03
13	0.000E-01	7.01[illegible]E+03
14	0.000E-01	7.440E+03
15	0.000E-01	7.85[illegible]E+03
16	0.000E-01	8.25[illegible]E+03
17	0.000E-01	8.63[illegible]E+03
18	0.000E-01	9.0[illegible]E+03
19	0.000E-01	9.38[illegible]E+03
20	0.000E-01	9.74[illegible]E+03
21	0.000E-01	1.01[illegible]E+04
22	0.000E-01	1.044E+04
23	0.000E-01	1.07[illegible]E+04
24	0.000E-01	1.107E+04
25	0.000E-01	1.13[illegible]E+04
26	0.000E-01	1.16[illegible]E+04
27	0.000E-01	1.19[illegible]E+04
28	0.000E-01	1.22[illegible]E+04
29	0.000E-01	1.24[illegible]E+04
30	0.000E-01	1.27[illegible]E+04
31	0.000E-01	1.296E+04
32	0.000E-01	1.3[illegible]E+04
33	0.000E-01	1.34[illegible]E+04
34	0.000E-01	1.36[illegible]E+04
35	0.000E-01	1.386E+04
36	0.000E-01	1.40[illegible]E+04
37	0.000E-01	1.42[illegible]E+04
38	0.000E-01	1.44[illegible]E+04
39	0.000E-01	1.46[illegible]E+04
40	0.000E-01	1.48[illegible]E+04
41	0.000E-01	1.505E+04
42	0.000E-01	0.000E-01

SECTION B-5

REFERENCES

B-1. Novotny, V. and G. Chester "Handbook of Nonpoint Pollution: Sources and Management," Van Nostrand Reinhold Company, New York, 1981.

B-2. Thibodeaux, L.J., "Chemodynamics: Environmental Movement of Chemicals in Air, Water and Soil," John Wiley & Sons, Inc., New York, 1979.

B-3. Helston, J. C. and P. C. Kaestner, "Risk Methodology for Geologic Disposal of Radioactive Waste: Model Description and User Manual for Pathways Model," NUREG/CT-1636 (SAND 78-1711), Sandia National Laboratories, Albuquerque, New Mexico, March 1981.

B-4. Patterson, M. R., et al., "A User's Manual for the FORTRAN IV Version of the Wisconsin Hydrologic Transport Model," ORNL-NSF-EATC-7, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 1974.

B-5. Killough, G. G., et al., "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities," ORNL/NUREG/TM-190, Oak Ridge National Laboratory, Oak Ridge, Tennessee, June 1978.

B-6. Egbert, S. D., et al., "FIIDOS-Fallout Inventory and Inhalation Dose to Organs," Unpublished Report, Science Applications, Inc., Schaumburg, Illinois, July 1981.

B-7. Glasstone, S. and P. J. Dolan, "The Effects of Nuclear Weapons," U. S. Department of Defense and Energy, Washington, D. C., 1976.

B-8. Onishi, Y., et al., "Critical Review: Radionuclide Transport, Sediment Transport, and Water Quality Mathematical Modeling; and Radionuclide Adsorption/Desorption Mechanisms," NUREG/CR-1322 (PNL-2901), Pacific Northwest Laboratory, Richland, Washington, January 1981.

B-9. Schreckhise, R. G., "Simulation of the Long-Term Accumulation of Radiocontaminants in Crop Plants," PNL-2636, Pacific Northwest Laboratory, Richland, Washington, March 1980.

B-10. Stumm, W. and J. J. Morgan, "Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters," John Wiley & Sons, Inc., New York, 1981.

B-11. "Versaplot-07 Graphics Programming Manual," Publication No. 5721-02, Edition No. 2, Versatec, Santa Clara, California, July 1978.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Armed Forces Radiobiology Rsch Institute
Defense Nuclear Agency
ATTN: Director

Armed Forces Staff College
ATTN: Library

Assistant Secretary of Defense
International Security Affairs
ATTN: ISA/[illegible]

Assistant Secretary of Defense
[illegible] Analysis & Evaluation
ATTN: [illegible]
ATTN: [illegible]
ATTN: [illegible]

Assistant to the Secretary of Defense
[illegible]
ATTN: [illegible]

[illegible]

DEPARTMENT OF DEFENSE (Continued)

Field Command
Defense Nuclear Agency
ATTN: FCPR
ATTN: FCPRF, T. Wells
ATTN: FCT, [illegible]
ATTN: FCTT, W. Summa
[illegible] ATTN: FCP[illegible]

Interservice Nuclear Weapons School
ATTN: Document Control

Joint Strat Tgt Planning Staff
ATTN: [illegible]
ATTN: [illegible]
ATTN: [illegible]
ATTN: [illegible] Nat Strat Tgt List Dir

National Defense University
ATTN: [illegible]

Office of the Sec of Defense
[illegible]
ATTN: [illegible]
ATTN: Military Assistant
ATTN: [illegible]

[illegible]

DEPARTMENT OF THE ARMY

[illegible]
ATTN: DAMI-[illegible]

[illegible]
ATTN: DAMO-[illegible]
ATTN: DAMO-[illegible]
ATTN: DAMO-[illegible]
ATTN: Technical Advisor
ATTN: DAMO-[illegible] Firepower Div
ATTN: DAMO-[illegible] Nuclear Div

[illegible] Staff for Rsch Dev & Acq
ATTN: DAMA-[illegible]

Harry Diamond Laboratories
ATTN: DELHD-[illegible]
ATTN: DELHD-[illegible], Tech Dir
ATTN: DELHD-[illegible]
ATTN: [illegible] Commander Tech Dir, Div Dir

DEPARTMENT OF THE ARMY (Continued)

US Army Armament Rsch Dev & Cmd
    ATTN: DRDAR-LCN-E

US Army Ballistic Research Labs
    ATTN: DRDAR-TSB-S
    ATTN: DRDAR-VL

US Army Chemical School
    ATTN: ATZN-CM-CC

US Army Cmd & General Staff College
    ATTN: DTAC
    3 cy ATTN: Combined Arms Research Library
    3 cy ATTN: ATZZL-CAD-LN

US Army Engineer School
    ATTN: Library

US Army Europe and Seventh Army
    ATTN: AEAGC-O-W
    ATTN: AEAGD-MM (DCSLOG, Mun & Msl Div)
    3 cy ATTN: DCSI-AEAGB-PDN

US Army Forces Command
    ATTN: AF-OPTS

US Army Foreign Science & Tech Ctr
    ATTN: DRXST-SD-1

US Army Infantry Ctr & Sch
    ATTN: ATSH-CTD

US Army Intel Threat Analysis Det
    ATTN: IAX-ADT

US Army Intelligence Center & School
    ATTN: ATSI-CD-CS

US Army Materiel Dev & Readiness Cmd
    ATTN: DR DE-D

US Army Materiel Sys Analysis Actvy
    ATTN: [illegible]

US Army Mobility Equip R&D Cmd
    ATTN: DRDME-WC, Technical Lib
    ATTN: DRDME-RT, [illegible]

US Army Nuclear & Chemical Agency
    ATTN: Library
    3 cy ATTN: MONA-OPS, [illegible] Hatway
    3 cy ATTN: MONA-[illegible]

US Army TRADOC Sys Analysis Actvy
    ATTN: ATAA-TAC

US Army Training and Doctrine Cmd
    ATTN: ATCD-FA

US Army War College
    ATTN: Library
    ATTN: War Gaming Facility
    ATTN: AWCAC, [illegible] Braden (Dept of Tactics)

USA Military Academy
    ATTN: Document Library

USAFACFS
    ATTN: ATZR-M[illegible]

DEPARTMENT OF THE ARMY (Continued)

USA Missile Command
    ATTN: DRSMI-YDR
    ATTN: DRSMI-RH

V Corps
    ATTN: G-2
    ATTN: Commander
    ATTN: G-3

VII Corps
    ATTN: G-2
    ATTN: G-3
    ATTN: Commander

DEPARTMENT OF THE NAVY

Anti-Submarine Warfare Sys Proj Ofc
    ATTN: PM-4

Charleston Naval Shipyard
    ATTN: Commanding Officer

David Taylor Naval Ship R & D Ctr
    ATTN: Code 174
    ATTN: Code 17[illegible], J. Sykes
    ATTN: Code 175[illegible], W. Conley
    ATTN: Code 142-3

Marine Corps
    ATTN: [illegible] Strategic Plans Div
    ATTN: Code [illegible]-31
    ATTN: [illegible] Requirements Div

Marine Corps Dev & Education Command
    ATTN: Commander

Naval Air Development Center
    ATTN: Code [illegible]

Naval Air Systems Command
    ATTN: Code [illegible]

Naval Intelligence Support Ctr
    ATTN: NIS-4
    ATTN: NISC-3[illegible]

Naval Material Command
    ATTN: MAT-046
    ATTN: MAT-[illegible]

Naval Ocean Systems Center
    ATTN: J. Hooper
    ATTN: R. Hammond

Naval Postgraduate School
    ATTN: Code 1424, Library
    ATTN: Code 56PR

Naval Research Laboratory
    ATTN: Code 2627

Naval Sea Systems Command
    ATTN: SEA-406
    ATTN: SEA-06[illegible]
    2 cy ATTN: SEA-6431[illegible]

Naval Submarine School
    ATTN: Commanding Officer

DEPARTMENT OF THE NAVY (Continued)

Naval Intelligence Command
ATTN: NIC-01

Naval Surface Force, Atlantic
ATTN: Commander

Naval Surface Force, Pacific
ATTN: Commander

Naval Surface Weapons Center
White Oak Laboratory
ATTN: Code F30
ATTN: Code U41
ATTN: Code R14
ATTN: Code F31

Naval Surface Weapons Center
ATTN: Code Du-502, E. Freiling

Naval War College
ATTN: Code E-11 (Tech Service)

Naval Weapons Center
ATTN: Code 32607, E. Thompson

Naval Weapons Evaluation Facility
ATTN: Technical Director
ATTN: G. Binns

Navy Field Operational Intelligence Office
ATTN: Commanding Officer

Newport Laboratory
Naval Underwater Systems Center
ATTN: R. Walsh

Nuclear Weapons Tng Group, Pacific
ATTN: Nuclear Warfare Department

Nuclear Weapons Tng Group, Atlantic
ATTN: Nuclear Warfare Department

[illegible]

DEPARTMENT OF THE NAVY (Continued)

Surface Warfare Development Group
ATTN: Commander

Surface Warfare Officers School Cmd
ATTN: Combat Systems Dept

US Atlantic Fleet
ATTN: Code J-5
ATTN: Code N-3
ATTN: Code N-22

US Naval Air Forces, Pacific Fleet
ATTN: Commander

US Naval Air Forces, Atlantic Fleet
ATTN: Commander

Commander-in-Chief, US Naval Forces, Europe
ATTN: N54

US Navy Second Fleet
ATTN: Commander
4 cy ATTN: ACOS Tac D&E Div

US Navy Seventh Fleet
ATTN: Commander

US Navy Third Fleet
ATTN: Commander

Commander-in-Chief, US Pacific Fleet
ATTN: CINC
ATTN: Code N2

US Submarine Force, Atlantic Fleet
ATTN: Commander

US Submarine Force, Pacific Fleet
ATTN: Commander

DEPARTMENT OF THE AIR FORCE

Air Force IN
ATTN: IN (Estimates)

Air Force Test & Evaluation Center
ATTN: [illegible]

Air Force Weapons Laboratory, AFSC
ATTN: [illegible]
ATTN: [illegible]

Air University Library
ATTN: [illegible]

Assistant Chief of Staff
Studies & Analyses
ATTN: [illegible]
ATTN: [illegible]
ATTN: [illegible]

[illegible]

[illegible]

DEPARTMENT OF THE AIR FORCE (Continued)

Deputy Chief of Staff
Research, Development, & Acq
ATTN: AFRDQR
ATTN: AFRD[illegible]
4 cy ATTN: AFRD-M (Spec Asst for MX)

Deputy Chief of Staff/XOX
Operations and Plans
ATTN: AFXOXFM (Plns, Frc Dev Mun Plns)
ATTN: Dir of Plans, AFXOX

Foreign Technology Division, AFSC
ATTN: SD
ATTN: [illegible]

Commander-in-Chief
Pacific Air Forces
ATTN: IN
ATTN: [illegible]

Strategic Air Command
ATTN: SA[illegible] IN

Tactical Air Command
ATTN: TA[illegible]
ATTN: TA[illegible]
ATTN: TA[illegible]
ATTN: TA[illegible]
ATTN: TA[illegible]
ATTN: TA[illegible]

[illegible] Air Force Academy Library
ATTN: Library

[illegible] Air Force Scientific Advisory [illegible]
ATTN: [illegible]

Commander-in-Chief
[illegible] Air Forces in Europe/DOAI
ATTN: [illegible]

Commander-in-Chief
[illegible] Air Forces in Europe/[illegible]
ATTN: [illegible] (Ops Anal)

Commander-in-Chief
US Air Forces in Europe/[illegible]
ATTN: [illegible]

Commander-in-Chief
[illegible] Air Forces in Europe/IN
ATTN: [illegible]

Commander-in-Chief
[illegible] Air Forces in Europe/[illegible]
ATTN: [illegible] Plns

Commander-in-Chief
Readiness Command
ATTN: [illegible]

Commander-in-Chief
United States Central Command
[illegible] ATTN: [illegible] MacDonald

[illegible] School of Aerospace Medicine
ATTN: Radiation Science Div

OTHER GOVERNMENT AGENCIES

Central Intelligence Agency
ATTN: OSWR/NED
ATTN: OSR/SE/F

Federal Emergency Management Agency
ATTN: Asst Assoc Dir for Rsch, [illegible]
ATTN: Ofc of Rsch/NP, D. Benson

US Arms Control & Disarmament Agcy
ATTN: [illegible]
ATTN: A. [illegible]

US Department of State
Office of Security
ATTN: [illegible]

NAT[illegible]

NAT[illegible] SHAPE
ATTN: [illegible]

DEPARTMENT OF ENERGY CONTRACTORS

University of California
Lawrence Livermore National Lab
ATTN: [illegible]
ATTN: [illegible]
ATTN: [illegible]
ATTN: [illegible]

[illegible] National Laboratory
ATTN: [illegible]
ATTN: [illegible]
ATTN: [illegible]

Sandia National Lab
ATTN: [illegible]
ATTN: [illegible]
ATTN: [illegible]

Sandia National Lab, [illegible]
ATTN: [illegible]

DEPARTMENT OF DEFENSE CONTRACTORS

Academy for Interscience Methodology
ATTN: N. [illegible]

Atmospheric Science Assoc
ATTN: H. Normant

BDM Corp
ATTN: [illegible] Morgan
ATTN: [illegible] Bradley

[illegible]
ATTN: [illegible]

Kaman Sciences Corp
ATTN: [illegible]
ATTN: [illegible] Shelton
ATTN: [illegible]

Kaman Tempo
ATTN: DASIAC

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

McDonnell Douglas Corp
ATTN: Technical Library Services

McLean Research Center, Inc
ATTN: W. Schilling

McMillan Science Associates, Inc
ATTN: W. McMillan

Mission Research Corp
ATTN: Tech Library

Pacific-Sierra Research Corp
ATTN: H. Brode, Chairman SAGE
ATTN: G. Lang

Pacific-Sierra Research Corp
ATTN: G. Moe
ATTN: D. Gormley

R&D Associates
ATTN: J. Lewis
ATTN: F. Field
ATTN: R. Montgomery
ATTN: P. Haas
ATTN: J. Marcum

Science Applications, Inc
ATTN: C. Whittenbury
ATTN: J. Martin
ATTN: M. Drake

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

R&D Associates
ATTN: J. Bengston
ATTN: H. Cooper
ATTN: A. Polk
ATTN: W. Houser
ATTN: J. Thompson

Santa Fe Corp
ATTN: D. Paolucci

Science Applications, Inc
ATTN: J. Goldstein
ATTN: J. McGahan
ATTN: W. Layson

Science Applications, Inc
ATTN: D. Kaul
ATTN: J. Phillips
ATTN: J. Roberts
ATTN: R. Sievers
ATTN: R. Gminder

System Planning Corp
ATTN: J. Jones
ATTN: G. Parks
ATTN: S. Shrier

DAT
FILM